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Stratigraphy, Geochronology, Petroleum Resources

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FOREWORD

This volume of Conference Proceedings brings together written versions of most of the contributions presented during the Golovkinsky Stratigraphic Meeting, which took place at Kazan Federal University, Kazan, Russia, September 24-28, 2019. This was the third of these conferences, named after the outstanding geologist, professor of Kazan University Nikolai Golovkinsky (1834-1897). Previous conferences were held in 2014 and 2017 in Kazan Federal University and were attended by scientists from 14 countries. The proceedings of these meetings have been published (Proceedings of Kazan Golovkinsky Stratigraphic Meeting “Carboniferous and Permian Earth systems, stratigraphic events, biotic evolution, sedimentary basins and resources”, Kazan (2014) and Advances in Devonian, Carboniferous and Permian Research: Stratigraphy, Environments, Climate and Resources: Filodiritto Editore Bologna, Italy (2017)).

Nikolai Golovkinsky’s contribution to geology is enormous, but unfortunately is still relatively less known outside Russia. In his works of 1868-1869 he preceded Walther (1894) in showing that sediments of the same facies continuously observed from shore to basin are not of the same age. This was the essential demonstration of the real complex structure of a geological space-time system. He was also the first to show that the depositional structure with a vertical succession of facies results from facies originally laterally juxtaposed to each other, which by the 1970s has become the basis for modern sequence stratigraphy.

The conference aimed to create a forum for further discussion on the integration of a range of geological information on the Paleozoic Era. The call for papers was addressed to scholars in the fields of paleontology, stratigraphy, geochemistry, mineralogy, geophysics, and mineral resources.

The conference provided a setting to discuss recent developments in a wide variety of topics concerning the Upper Paleozoic, including Biostratigraphy, Chemostratigraphy, Biogeography, Paleoclimatic, Facies, Mineralogy, Lithology, Geophysical methods and Resources, with an emphasis on the Permian-Triassic boundary (PTB) and other boundaries within the Upper Paleozoic. Contributions on issues of facies and paleogeographical interpretations were also welcomed, as were papers on climate, biota and changes in the sedimentary environment during the Late Paleozoic. Various aspects of sedimentary succession and rock composition and properties were developed by high-precision methods and presented in contributions discussing bedding patterns, grain size changing, coal seams, carbonate deposition, incised valley formation, and conventional and unconventional mineral resource prospects in Europe and Asia. The general topics and spirit of the Golovkinsky meetings are in full agreement with the high priority stratigraphic tasks of the International Commission on Stratigraphy, and cover such important aspects of its work as GSSP selection, and developing high-precision regional stratigraphic schemes and interregional correlations.

This conference volume is aimed at both academics and applied geologists, and provides a forum for a number of perspectives, based on either theoretical analyses or empirical case studies that will foster dialogue and the exchange of ideas.

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Genetic and Biological Features of Upper Paleozoic Reef Ecosystems from the North-eastern European Platform

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Abstract

The results of a paleoecological study of reef ecosystems in the Upper Paleozoic organic structures formed on the northeast margin of the European Platform (in modern coordinates) are presented. The main communities, microbial and metazoan associations, which are important designers at various stages of ecological continuity, are considered. Accordingly, their role in reefal as well as in microbial, skeletal and mud mound ecosystems is considered.

The development of ecological successions in genetically diverse organic frameworks resulted from regional and global changes in tectonics and the biosphere.

Keywords: community, reef ecosystem, ecological succession, mound, reef, Upper Paleozoic, NE-European Platform

Introduction

Late Paleozoic organic bodies of the north-eastern European Platform (NE-European Platform) are exposed in the Northern, Subpolar, Polar Urals, and in the Chernyshev, Chernov swells, and numerous Upper Devonian and Lower Permian organic buildups have been established from subsurface data in the Pre-Urals Foredeep and the Pechora Syncline (Fig. 1A).

The height of reef development was during the Early Devonian (Pragian-early Emsian) and is reflected by the development of the largest barrier reefs [1]. The Late Paleozoic reef-formation history on the NE-European Platform included some long intervals of atypical reef ecosystems, reflecting significant reorganizations of the biosphere. The most characteristic examples of such organic constructions are the Upper Devonian microbial, Upper Carboniferous-Lower Permian skeletal, and Asselian-Lower Sakmarian mud mounds (using terminology of [2]). According to [3], reef ecosystems, like any other ecosystem, develop according to certain “laws” – from initial unstable states or stages to more stable ones. In the absence of external stress factors, a directed process of succession may occur in the stages of the reef ecosystem from the initial (pioneer) – stabilization and colonization phases to the mature (climax) stage – diversification and dominant phases. Succession is controlled by the community, although the physical environment determines the nature and rate of change, as well as the limits of development. Various genetic types of organic structures are formed during each ecosystem stage. According to paleoecological studies, the ecological succession of reef ecosystems in these atypical organic constructions does not reach the mature stage [4], [5], [6], [7], [8], [9], [10], [11].

Geologic and Paleogeographic Setting

From west to east, the region studied includes the Timan Ridge, Pechora Syncline, Pre-Uralian Foredeep and Western Megazone of the Urals, including the Northern, Subpolar and
Polar Urals. The formation of the Ural fold belt (Uralides) began in the Late Devonian from the collision of the Magnitogorsk island arc and the passive edge of the European Platform [12]. The folded Late Pre-Cambrian basement is exposed on the uplift arches on the Kanin-Timan Ridge, the Urals, Pay-Khoy and southern island of Novaya Zemlya. The Western-Uralian Megazone is a complex dislocated eastern margin of the pericratonic subsidence overlain with allochthones composed of deep-water complexes. The Paleozoic strata formed on or close to the NE-European Platform, equivalent to the Pechora Plate, during gradual subsidence. The reef formation in the NE-European Platform was initiated by the opening of the Paleo-Ural Ocean at the Cambrian-Ordovician boundary and came to the end in the Sakmarian time of the Early Permian with the activation of collision processes. The carbonate platform margin was deformed by orogenic processes in the Paleo-Ural Ocean, and organic bodies rimmed a back stepped carbonate platform. The carbonate shelf margin was principally constructed by diverse benthic microbial and metazoans communities, which formed a laterally continuous facies tract, sometimes restricting shelf circulation causing limited water circulation conditions including evaporite sedimentation. The reefs and reef-like

Fig. 1. Map of the study area showing the location of Upper Paleozoic organic constructions in the northeast European platform (A), the distribution of main organisms in various organic structures (B) and the correlation between tectonic events, glaciations of Gondwana, extinction events and Hardy model (C).
units developed in a variety of environmental settings including platform margin, slope of intra-platform depressions, back-reef lagoons, and slope depression of the deformed platform margin. Palaeomagnetic and palaeoclimatic data, including the occurrence of widespread lagoon evaporates and carbonates characterized by particular benthic communities, are evidence that the study area was located within the latitudes 5° to 30° N in the Late Paleozoic [13]. Upper Paleozoic organogenous structures are widespread in the studied region and are characterized by a variety of framework-builders and reef-dwelling organisms.

Results of the Study of the Upper Paleozoic Reef Ecosystems

Upper Lochkovian-Lower Emsian and Upper Visean-Serpukhovian reef ecosystems

Mature ecological ecosystems are present only in the Upper Lochkovian-Lower Emsian and Upper Visean-Serpukhovian reefs, which formed on the shelf margin that corresponds now to the western slope of the northern part of the Urals (Figs. 1, 2). The Upper Lochkovian reef is well known in the Polar Urals. This is extensively dolomitized which has made interpretation difficult. The main reef is characterized by stromatolite mats encrusting skeletal and clastic fragments. The lower part of this is represented by an abundance of crinoids, brachiopods, rare bryozoans, and unidentifiable shells fragments. Brachiopods often form accumulations from various brachiopod species having bad preservation and porosity of shells. Large bulbous and laminar stromatoporoids, branching tabulate, and rare rugose corals together with stromatolite crusts predominantly comprise the reef’s middle part. *Girvanella*, *Renalcis*, and *Ikella* are occasionally recognized in the bound-stone fabric. Brachiopods (*Clorinda*, *Gypidula*, *Spirigerina*) are locally concentrated within microbial-stromatoporoid bound-stones in the upper part of the reef. Sometimes they form accumulations generated by a superposition of valves similar to shell bars. Extended thin-laminated microbial crusts of *Spongiostroma* type structure that form around clusters of bioclastic material are common in the uppermost part of the reef.

During the Pragian time, barrier reefs, well exposed and with differentiated lithology, allow recognition of frontal reef, reef flat, sometimes intra-reef lagoon as well as back-reef facies within these reefs. The reef ecosystems are mainly represented by a distinctive assemblage of the microbial-problematic hydroid *Ikella-Fistulella* and diverse green algae, especially lanciculids (*Lanicula, Planolancicula, Laniculella, and Voycarella*), dasyyclads (*Litanaia, Abacella, Dasyaporella, Antracoporella*) and rodophyta (*Demidella, Paralancicula*). The Pragian reefs have about 25 species of calcareous algae. The brachiopod *Karpinskia conjugula* and bivalve mollusk *Hercinella* concentrations are common in these reefs. In microbial-metazoan boundstones, stromatolitic crust *Pycnostroma* and *Spongiastroma* fabrics are mainly revealed, and diverse microbial assemblages, except for *Epiphyton*-like forms, consist of *Renalcis*, *Ikella*, *Girvanella*, *Rothpletzella*, *Garwoodia*, and *Hedstroemia*. The Lower Emsian ecosystems in the Northern and Polar Urals are characterized by the appearance of *Wetheredella-Stachyodes* and *Solenopora*-stromatoporoid associations and the ostracode *Moelleritina*. At that time, the Lemva reef in the Subpolar Urals consisted of the microbial-problematic hydroid *Ikella-Fistulella* consortium, associated with stromatoporoid-coral-microbial assemblages and diverse shelly fauna [14]. Abundant and diverse autotrophs, cyanobacteria and calcareous algae at the diversification stage demonstrate a resistance in reef ecosystems. The dominant stage of reef ecosystems is characterized by a wide development of metazoan and calcimicrobial communities, especially *Ikella-Fistulella*. 
The Late Visean-Serpukhovian reef is developed in the boundary area of the Polar/Subpolar Urals [1]. Late Visean goniatites are abundant, although they are impoverished in taxonomic respect. Massive bound-stones comprising rugose corals (*Lonsdaleia, Axophyllum, Hexaphyllia*), abundant brachiopods, gastropods, and crinoids occur in the lower part of the reef. Biohermal bound-stones contain codiaceans (*Masloviporidium, Calcifolium*), dasyclads *Konickopora*, and cyanobacteria (*Ortonella, Garwoodia, Renaclis, Micheldania*). According to [15], (foraminifera) (*Neoarchaediscus, Permodiscus, Asteroarchaediscus, Eolasiodiscus, Palaeotextularis, Eostaffella*) are represented by more than 50 species. Massive polybioclastic limestones with rare bryozoans but abundant foraminifera and brachiopods of the late Viséan-early Serpukhovian age form the upper part of the reef. Cephalopod-bivalves and brachiopod coquinas also occur. The most important frame-builders in this reef were cyanobacteria, green algae and bryozoans, with an optional role of crinoids and foraminifera. Stages in the ecological reef succession can be outlined.

**Upper Devonian microbial mound ecosystems**

During the Middle Frasnian-Famennian, a large complex of massive and bedded reefal bodies was established in the Northern and Subpolar Urals, in the Chernyshev Swell, and from subsurface data in the Pre-Urals Foredeep. Localization of buildups on the shelf was controlled by the position of starved basins. The Sher-Nyadejeta buildup in the Chernyshev Ridge was mostly constructed by stromatoporoid-microbial and microbial assemblages that bound skeletal
and non-skeletal material [16]. Crinoids, corals, brachiopods and laminar stromatoporoids are rich in the lower part. Thick laminar, branching and domed encrusting stromatoporoids, sometimes with Receptaculites concentrations, occur in the metazoan-microbial association.

Calified microbes, cyanobacteria, and algae (?) (Renalcis, Izhella, Shuguria, Epiphyton, Sphaerocodium, Girvanella, Chabakova, rare Ortonella, and Solenopora) are recognized in massive boundstones. The dominant organisms constructing the Upper Frasnian bound-stones were stromatoporoids and cyanobacteria, whereas the Famennian ones were mostly formed by microbial assemblages. In some places, stromatoporoid-microbial bound-stones comprise framework composed of the receptaculitids and stromatolites. The Renalcis-Izhella-Shuguria-Epiphyton associations are abundant, especially in the Frasnian of the Shar’yu mound in the Chernyshev Ridge, and in the Famennian they probably played an important encrusting and stabilizing rather than a frame-building role. Accumulations of brachiopod debris occur locally in microbial bioherms. Large brachiopods (Plectorhynchonella, Junnaellina, Cyrtospirifer, Chonetipustula, and Plicatifera) form lenticular bodies [4]. Echinoderm remains and some crinoid stem fragments have been found together with brachiopod shells, also rare calcareous sponge spicules, ostracodes, and Charophyta fragments occur. The microbial boundstones consist mainly of calcareous microbes or cyanobacteria (Renalcis, Girvanella, Rothpletzella, Izhella, Shuguria, Epiphyton, Sphaerocodium, Chabakova, rare Ortonella, Nuia, Shariiphyton), of solenoporids, and also contain calcispheres/radiolarians, foraminifera, and rare Charophyta [4]. Biostrome-like stromatolite crusts can form mats up to 10 m long.

According to [8, 16], the same microbial associations in the Famennian ecosystems are established from subsurface data sections. Fragments of ostracodes, gastropods, brachiopods, unidentified bioclastic material sometimes form small bodies. Calcified microbes and cyanobacteria (Renalcis, Girvanella) interspersed with microbial laminae, are associated with rare skeletal remains (ostracodes, foraminifera) and form stromatolitic encrustations on peloidal debris. At the stabilization stage, crinoids, corals, brachiopods and laminar stromatoporoids dominated together with calcimicrobial communities. At the colonization stage, metazoans – rugose corals, stromatoporoid and receptoculid sponges – are common, but frame-building organisms – various cyanobacteria communities and porostromate stromatolites play the main role, which led to self-sufficiency, but not sustainable ecosystems.

**Upper Carboniferous-Lower Permian skeletal mound ecosystems**

The Upper Carboniferous-Lower Permian skeletal mound ecosystems are widely developed in the Northern, Subpolar and Polar Urals, and Pre-Urals Foredeep. The reef ecosystems of skeletal mounds are dominated by sessile organisms, such as fenestrate bryozoans, green phylloid algae, hydroids, and Tubiphytes. Ecosystems of mounds are generally represented by associations of algal-bryozoan-Palaeoaplysina-small foraminifera with various metazoans (Fig. 1B). The stabilization stage is marked by accumulation of bioclastic sand or carbonate mud inhabited by mainly laminar Palaeoaplysina and green phylloid algae or branching bryozoans. At the second stage, the substrate is colonized by fenestrate bryozoans, with active participation of foraminifera, Tubiphytes or rare phylloid algae [10]. Generally, fossils are characterized by a broad taxonomic diversity: brachiopods, bryozoans, foraminifera, crinoids, ostracodes, gastropods, bivalves, echinoids, trilobites, hydroids, rugose corals, nautiloids, ammonoids, phylloid algae, problematic microfossils, and calcimicrobial communities. The skeletal mounds generally contain microbial-bryozoan, microbial-Palaeoaplysina, and microbial-phylloid and microbial-bryozoan-Tubiphytes associations. The green phylloid algae are represented mainly by Anchicodium, less commonly by Eugenophyllum. The fusulinid assemblage of the Kozhym skeletal mound in the Subpolar Urals is characterized by Globifusulina, Schwagerinformis, Pseudofusulina. At the stabilization stage (the Gzhelian part) of the mound there are phylloid algae, bryozoans, Tubiphytes, rare foraminifera, brachiopods, and heterogenic bioclasts. The

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colonization stage is characterized by numerous fenestrate bryozoan-Tubiphytes associations, Palaeoaplysina-microbial-bioclastic associations, brachiopod-rich coquinas, and foraminifera. Locally they are associated with ammonoids. In general, 31 brachiopod species are identified in this mound [17].

**Lower Permian mud mound ecosystems**

Microbial-bryozoan, microbial-Palaeoaplysina, microbial-phylloid and microbial-bryozoan-Tubiphytes associations are not common in mud mound ecosystems, compared to skeletal mound ecosystems. The Asselian-Lower Sakmarian mud mounds are currently identified in two sections: in the Northern Urals, Ilych River [9] and in the Polar Urals, Lek-Elets River [11]. These mounds are in many respects formed by the action of microorganisms (Renalcis, Givanella, and Tubiphytes). The ecosystem of the Rozya Kyrta mud mound on the Ilych River differs from the mud mound ecosystem on the Lek-Elets River by its great biodiversity, but they are similar in the absence of Palaeoaplysina and the presence of contacts with condensed deposits. The typical stages of ecological succession in the mud mounds were not observed; therefore, we can only indicate the trophic structure of the ecosystem found in the Rozya Kyrta mound, which consists of 5 steps [9]. The microbial community characterizes the first sublevel of the first level, and green algae – the second sublevel. The consumers are divided into two levels: bottom filter feeders (foraminifera, brachiopods, and reticulate bryozoans), above-bottom filter feeders (ramose bryozoans and crinoids) and omnivores ( gastropods, ostracodes, and trilobites).

**Factors affecting reef ecosystems and genesis of organic frameworks**

In the Late Paleozoic, global sea level falls was associated with periodic glaciations on Gondwana [18], the formation of the Ural folded system and, as a result, an increase in the activity of the Pechora Plate inversion processes (Figs. 1C, 2). They caused the erosion of large areas in the region. The deformation of the carbonate platform margin developed under changing basin paleolandscape and paleoecological conditions, increasing continental flow.

These factors caused the intensification of microbial communities’ biochemical activity and occurrence of eutrophic conditions in depressions of the epicontinental shallow-water sea.

Changes of the Late Devonian depositional environments can be grouped into two macroenvironments: submarine and subaerial [4]. The first is characterized by the prevalence of subtidal low or middle energy conditions, and the second, essentially by the development of supratidal environments. The paleoecological analysis of the submarine microfacies reveals anomalous marine conditions during their deposition. Restricted associations of calcified microbes, small calcispheres, and foraminifera were able to exist. The prolonged environmental stress in NE-European shelf habitats is mostly ascribed to the increased oxygen deficiency and/or unbalanced nutrient dynamics in the disturbed greenhouse climatic and active synsedimentary tectonic setting. Since the Early Carboniferous Epoch, the Mg/Ca ratio in seawater has shifted to an aragonite regime, and new ecosystem communities have begun to prevail (Figs. 1C, 2). The evolution of the reef ecosystems was determined by the change in the chemistry of ocean waters and the manifestation of their mesotrophism [19]. The role of metazoans as reef-formation organisms during this time fell sharply, as they had calcite skeletons [20].
Conclusion

Starting from the Early Devonian time, tectonic instability caused by the subduction process of the Uralian margin of the European Platform and island arcs contributed to periodic interruptions in the development of reef ecosystems, followed by the restoration of porostromate-containing reefs.

The Upper Lochkovian-Lower Emsian and Upper Visean-Serpukhovian reef ecosystems developed on the shelf margin. They show the prevalence of metazoan or metazoan-microbial communities that required an external source of nutrients in the pioneer stages of ecological succession. The Late Visean-Serpukhovian reef ecosystem developed during a short-term period from the preceding Late Devonian dominant microbial mounds and by a longer period from the Late Carbonaceous-Lower Permian skeletal mounds formation. Algae and bryozoans were the main reef-building organisms associated with less significant crinoids and foraminifera in the reef ecosystem.

The Middle Frasnian-Famennian reef ecosystems existed on the carbonate slopes of isolated shallow carbonate platforms and carbonate banks. These formed in wide depressions with uncompensated sedimentation and anoxic conditions within the tectonically differentiated shelf, and were characterized only by pioneering stages of ecological continuity. This is confirmed by the mass distribution of microbial associations, as well as by non-skeletal microbial carbonates.

The Upper Carboniferous-Lower Permian skeletal mounds developed on slopes of the retreating carbonate shelf and on the slopes of the newly formed uplifts. These were affected by anoxic near-bottom waters during the degradation of the carbonate platform as a result of the collision process. The ecosystems of the skeletal mounds are mainly characterized by broad taxonomic suites of metazoans: brachiopods, bryozoans, foraminifera, crinoids, ostracodes, gastropods, bivalves, echinoids, trilobites, hydroids, rugose corals, nautiloids, ammonoids, and problematic microfossils. Phylloid algae, hydroids, and calcimicrobial communities periodically formed small bioherms or banks on unsorted bioclastics. The skeletal mound ecosystems generally contain varieties of microbial-bryozoan, microbial-phyllloid, and microbial-bryozoan-Tubiphytes associations.

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Progress on the Ichnological Analysis of the Lower and Upper Kazanian Strata from the Volga Region (East European Platform, Russia)

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Abstract

This paper presents the progress of the ichnological analysis of the Lower and Upper Kazanian deposits of the Pechishchi and Sentyak sections from the Volga-Kama Basin (East-European Platform, Russian Federation). The ichnological data consists of a diverse invertebrate ichnofauna, including seven ichnogenera assigned to eight ichnotaxa, which are: Lockeia siliquaria, Oblongichnus solodukhoi, Ophiomorpha irregularis, Skolithos cf. verticalis, Skolithos isp., Thalassinoides suevicus, Palaeophycus tubularis, Phycodes cf. palmatus. These ichnotaxa are mostly ascribed to suspension- and deposit-feeding behaviour of the diverse organism groups. They are mainly referred to polychaete worms, vermiform or worm-like, amphipod crustaceans and/or crustacean-like, thalassinidean shrimps, sea anemones, bivalves and other mollusc organisms as tracemaker candidates, that colonised the open shallow-marine ecosystem during the Kazanian time.

Keywords: Kazanian, invertebrate ichnofauna, Behaviour, Palaeoenvironment

Introduction

The East European Platform is a type region for the Permian system, considered to be one of the largest Permian sedimentary basins in the world. The Permian deposits cover stratigraphically a continuous succession representing more than 45 Ma of Earth’s history. In the study area, these deposits are composed of series; completely marine deposits, marine and continental transitional successions, and entire continental deposits. Marine-continental (transitional) formations are the most difficult to interpret in terms of palaeoenvironment, palaeoecology and palaeoclimate due to the lack of reliable stratigraphic (biotic and abiotic) markers for interregional correlations [1]. However, these formations cover a large part of the East European Platform, and an important thickness of it. Iconological studies are so rare on such deposits, that some invertebrate trace fossils were reported in a conference abstract, and field guide [2], [3], [4] and [5] mentioned thinly horizontal and vertical fucoid that could be considered here as invertebrate traces. [6] gives a short overview on the invertebrate ichnofauna of the Upper Kazanian deposits. Recently, advanced ichnotaxonomic analysis of trace fossils coming from the Upper Kazanian deposits led to the establishment of a new ichnogenus and ichnospecies Oblongichnus solodukhoi [7].

Although trace fossils provide conjectural information on the nature of the living organism which produced the trace fossils, they also provide a unique window into behaviour that body fossils cannot provide, as well as into the palaeoenvironmental and palaeoecological conditions of the deposition during the time of their formation. The present paper provides an overview of the progress of the ichnological analysis of the Lower and Upper Kazanian (Middle Permian)
deposits from Volga region. Thus, the invertebrate trace fossils provide elements for palaeoenvironmental and palaeoecological interpretations, and give the behaviour of invertebrate fauna communities of the study area.

**Material and Methods**

The present ichnological study is based on more than twenty specimens, which are housed predominantly in the collection of the Geological Museum of Kazan Federal University. A few specimens are reposed at the Natural History Museum of the Republic of Tatarstan, Russian Federation. Specimens were photographed in the laboratory. The measurements of the best-preserved specimens are carried out following standard procedural practice in invertebrate ichnology [8]. The different parameters of trace morphology and patterns are recorded.

**Geological Setting**

The Volga and Kama River regions are part of the Russian Plate, belonging to the East European Platform (Fig. 1). The Permian deposits comprise three parts, subdivided into stratigraphic units of the Russian General Stratigraphic Scale (RGSS): (i) the completely marine succession (Cisuralian Series); (ii) the marine-continental (transitional) succession represented by the Ufimian, Kazanian and Urzhumian stages; (iii) the completely continental succession consisting of Severodvinian and Vyatkian stages. The Ufimian stage tentatively coincides with the uppermost part of the Kungurian Stage of the International Chronostratigraphic Chart (ICC) [3]. The Kazanian and Urzhumian stages are correlated with the Roadian and Wordian, respectively. The last two constitute the Biarmian Series (= Lower and Middle Guadalupian of the ICC). The Severodvinian and Vyatkian stages represent the Tatarian Series of the RGSS, tentatively correlated with the Capitanian stage (= Upper Guadalupian of the ICC) and the Lopingian Series of the ICC. The Middle and Upper Permian are well exposed in many outcrops due to the topography (up to 200 m) and ongoing mining activities. The reported invertebrate ichnofossil assemblages come from marine strata, belonging to the Early and Late Kazanian ages, that constitute the lower part of the Biarmian Series (Fig. 1). The distribution of invertebrate ichnoassemblages described here differs from stage to stage, in terms of both diversity and abundance. The Lower Kazanian deposits consist of grey to brownish alternative series of shale, limestone, marlstone and sandstone. This is overlain by the Upper Kazanian series, represented by yellowish to brownish fine grained, gently laminated limestone and dolostone. Both stages are characterized by the presence of a high degree of bioturbation and by the presence of shell pavements.

**Description of Trace Fossils**

In terms of ichnology, the ichnoassemblages described herein are reported as being from different localities (Sentyak and Pechishchi) of the Kazanian stage. The Lower and Upper Kazanian strata have so far yielded a diverse invertebrate ichnofauna consisting of seven ichnogenera within eight ichnotaxa including *Lockeia siliquaria*, *Oblongichnus solodukhoi*, *Ophiomorpha irregularis*, *Skolithos* cf. *verticalis*, *Skolithos* isp., *Thalassinoides suevicus*, *Palaeophycus tubularis*, *Phycodes* cf. *palmatus*.

**Ichnogenus Lockeia** James, 1879

*Lockeia siliquaria* James, 1879 (Fig. 2A): Horizontal to sub-horizontal, symmetrical to asymmetrical, smooth walled, non-ornamented almond-shaped elongated burrows. Some invertebrate burrows have subcircular or subrounded-to-elliptical traces, which are tapered at
both extremities, although a longitudinal faint crest may be present in some burrows. The burrows are mainly preserved in convex hypo relief within fine-grained sandstone [9].


**Ichnogenus Oblongichnus** Bel Haouz, Lagnaoui et Silantiev, 2019

**Oblongichnus solodukhoi** Bel Haouz, Lagnaoui et Silantiev, 2019 (Fig. 2B): Simple, straight to slightly curved, unbranched, unornamented, smooth walled burrow, oriented in multiple directions, sub rectangular to oblong in cross-section. It is characterised by a thick lining with internal and external very fine-grained mucous layers. Burrow fill is typically massive and similar to the host rock lithology. This ichnotaxon has been described based on
material coming from Seryi Kamen Member of Pechichshi Beds of the Upper Kazanian Stratotype Section [7].

Fig. 2. Invertebrate traces from the Lower and Upper Kazanian deposition of the Pechishchi section. A. Lockeia siliquaria. B. Oblongichnus solodukhoi, C. Ophiomorpha irregularis, D. Skolithos cf. verticalis, E. Skolithos isp., F. Thalassinoides suevicus, G-H. Palaeophyxis tubularis, I. Phycodes cf. palmatus

**Ichnogenus Ophiomorpha** Lundgren, 1891

*Ophiomorpha irregularis* Frey, Howard et Pryor, 1978 (Fig. 2C): Meandering to winding horizontal, cylindrical, hypichnial meander maze burrow, with pelleted-lined walls. The burrow is preserved as a convex hypichnial in brownish-red fine-grained sandstones from the Lower Kazanian strata (Sentyak section) [10], [11]

**Ichnogenus Skolithos** Haldeman, 1840

*Skolithos cf. verticalis* Hall, 1843 (Fig. 2D): Simple, unbranched, straight to slightly curved, subvertical to slightly inclined cylindrical invertebrate burrow. The burrow is preserved as endichnia in yellow limestones. The burrow wall is smooth and the margins are clearly distinct and irregular. The filling is brownish-grey mudstones different from the host rock.

*Skolithos* isp. (Fig. 2E): Simple, unbranched, do not interpenetrate, straight to curved, vertical to slightly inclined cylindrical tunnel burrows. The burrows are preserved as endichnia in grey fine- to medium-grained carbonate sediments. J-shaped tunnel burrows are present as well. These burrows are reported from Yadrenyi Kamen, Opoki and Podluzhnik Members of the Upper Kazanian.

**Ichnogenus Thalassinoides** Ehrenberg, 1944

*Thalassinoides suevicus* Rieth, 1932 (Fig. 2F): Hypichnial to endichnial, predominantly horizontal to slightly inclined, elliptical to flattened cylindrical, smooth-walled, unlined burrow
systems. They show polygonal, Y- to T-shaped branching structures, straight to slightly winding. They are reported from Yadrenyi Kamen Member of the Upper Kazanian strata.

**Ichnogenus Palaeophycus** Hall, 1847  
*Palaeophycus tubularis* Hall, 1847 (Fig. 2G-H): Unbranched, smooth walled, essentially cylindrical to subcylindrical, subcircular to elliptical in the vertical sections, straight to slightly curved, predominantly horizontal to slightly oblique simple burrows. These burrows are thinly lined and passively filled with the same lithology as the host rock. They are reported mainly from Lower Kazanian deposits in Sentyak section.

**Ichnogenus Phycodes** Richter, 1850  
*Phycodes cf. palmatus* Hall, 1852 (Fig. 2I): Bundled splayed pattern of horizontal, flattened, cylindrical to subcylindrical burrows originating from a central base tunnel and fanning outwards in a broom-like pattern of individual burrows, unlined, linear, fasciculate, falcate, or circular.

**Behavioural and Paleoenvironmental Implications**

The small oblong horizontal structures, which resemble an almond projecting above the surface, match the diagnostic features of the ichnogenus *Lockeia*. This ichnogenus is considered a resting trace (cubichnion) of the burrowing bivalves [19]. *Lockeia* is produced by bivalves in various environments, but most commonly in shallow-marine settings [19]. It has been recorded in deep marine and non-marine sediments as well [20].  

*Oblongichnus* is variably oriented. The burrow’s fill is similar to the host rock. This, along with evidence of passive filling, and a thick lining, could represent a combination of feeding and dwelling behaviours of suspension-feeding organisms, similar to *Palaeophycus* [7], [21].  

However, it could be also interpreted as domicchia of bivalves. The most likely producers of *Oblongichnus solodukhoi* are elongated and ultra-elongated bivalves [7].  

*Ophiomorpha* is more or less smooth walled on the interior and pelletoidal-walled on the exterior. The diagnosis of the ichnogenus *Ophiomorpha* refers to simple to complex burrow systems lined at least partially with agglutinated pelletoidal sediment [22]. This ichnotaxon is one of the most widely known and easily recognisable trace fossils [11], which is common in many high-energy marine palaeoenvironments [11]. *Ophiomorpha* are considered to be both suspension- and deposit-feeders [23], thus shrimp-like arthropods are the most likely tracemakers who are able to produce similar traces [11].  

The ichnogenus *Skolithos* is an ichnotaxon index of the *Skolithos* ichnofacies [25]. *Skolithos* mainly indicates a relatively high energy hydrodynamic in shallow-water settings of the nearshore to marginal-marine environments [26]. Due to the wide stratigraphic range, *Skolithos*-like burrows have been referred to various organism groups as potential tracemakers, including worm-like organisms such as priapulids and polychaetes. Phoronids were also considered to be producers of the Palaeozoic *Skolithos* and younger strata [26].  

*Thalassinoides* is a typical cross-facies trace fossil that usually spreads in every environment during the Phanerozoic and occurs everywhere, from shallow facies mainly in the Palaeozoic and Mesozoic, to very deep environments in the Tertiary. The tracemakers of *Thalassinoides* are usually referred to thalassinidean shrimp [27] or decapod crustaceans [28].  

The ichnogenus *Palaeophycus* is known as a component of *Cruziana* Ichnofacies, and subordinately, associated with the *Skolithos, Zoophycos* and *Nereites* ichnofacies. It is reported from a wide range of marine and nonmarine environments; however, it is also common in shoreface and offshore deposits [29]. Generally, *Palaeophycus* is interpreted as a combined
feeding and dwelling (domichnion) behaviour of suspension feeding organisms [21]. The most likely producers of *Palaeophycus* are vermiform or worm-like organisms (e.g., annelids).

*Phycodes* is interpreted as a fodinichnion and occur commonly in, but are not restricted to, the shallow marine *Cruziana* ichnofacies [20]. *Phycodes* is believed to be a reliable indicator of shallow water conditions in marine environments and a characteristic trace fossil of the *Cruziana* ichnofacies [29], occurring in low-energy environments with relatively stable substrates. The potential tracemakers could be any burrowing organisms (e.g., worms, annelids).

**Conclusions**

The Kazanian deposits of the Volga-Kama Basin, a part of the East European Platform, have so far yielded a moderately diverse invertebrate ichnofauna, including seven ichnogenera, which are *Lockeia*, *Oblongichnus*, *Ophiomorpha*, *Palaeophycus*, *Phycodes*, *Skolithos*, *Thalassinoides*. Generally, these ichnotaxa are mostly interpreted as behaviours of suspension-feeding and deposit-feeding animals, which can be referred to polychaete worms, vermiform or worm-like (e.g., annelids), amphipod crustaceans and/or crustacean-like, thalassinidean shrimps, sea anemones, bivalves and other mollusc organisms as tracemakers candidates, that colonised the Kazanian Sea. The presence of these ichnotaxa indicates at a shallow-marine environment of the ichnofossil-bearing strata.

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Bivalve Trace Fossils from the Kazanian Strata of the Volga Region (East European Platform, Russia): Ethological Implications

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Abstract

This paper presents a comprehensive ichnological analysis of invertebrate traces, that are possibly produced by bivalve organisms, and that have been found in the Lower and Upper Kazanian deposits of the Volga Region. The reported invertebrate ichnofauna include the ichnogenera Lockeia, Oblongichnus, Protovirgularia, Ptychoplasma, and Arenituba. These ichnotaxa are ascribed to cubichnion (temporary resting trace), domichnion (three-dimensional habitation burrow created by tracemaker), combining feeding and habitation, repichnia (tracks and trails created while moving across the sediment surface) and crawling behaviours of burrowing suspension-feeding bivalves. Respectively, Arenituba is ascribed to post-depositional domichnia and/or fodinichnia (three-dimensional burrow characterized by the combined functions of deposit feeding and habitation) that could also be produced by bivalves. These ichnotaxa occur in open shallow-marine settings.

Keywords: Kazanian, Bivalve trace fossils, Behaviour, Ethological implications

Introduction

Although trace fossils provide conjectural information on the nature of the trace producer while it was still alive, they also help us to understand their producer’s behaviour in a way that body fossils cannot provide, as well as the palaeoenvironmental and palaeoecological conditions during the time of their formation. This paper focuses on the invertebrate traces and burrows possibly produced by bivalves. This study belongs to a research project dealing with the ichnological analysis of ichnofauna reported from the Lower and Upper Kazanian (Middle Permian) deposits of the Volga region. Thus, the invertebrate trace fossils provide evidence for palaeoenvironmental and palaeoecological interpretations, and towards the behaviour of invertebrate fauna communities of the study area.

Variable traces and burrows are produced by bivalve fauna, which includes vertically oriented filter or interface-deposit feeding, rapid vertical escape, horizontal grazing (horizontal feeding traces on the surface of the substrate), or resting behaviour. Thus, the most commonly known traces produced by bivalves are Gastrochaenolites, which represent domicinia structures of bivalves; Hillichnus, which is interpreted as combined deposit feeding and chemosymbiosis behaviours, Lockeia which is interpreted as a resting trace. However, they also represent the relatively stable domicile of filter-feeding bivalves; Protovirgularia was considered to be a combined locomotion and feeding behaviour; and Ptychoplasma are suggested to be the result of locomotion behaviour. Recently, a newly-established ichnogenus, Oblongichnus, was interpreted as dwelling structure, but could be also a filter-feeding behaviour. The Lower and Upper Kazanian yield only a moderately diverse ichnofauna that
could be referred to bivalves as potential tracemakers, which are the ichnogenera *Lockeia*, *Oblongichnus*, *Protovirgularia*, *Ptychoplasma*, and *Arenituba*.

### Material and Methods

The presented ichnological study is based on several specimens collected from the Lower and Upper Kazanian depositions of the Volga region. The specimens are stored at the collection of the Geological Museum of Kazan Federal University and the Natural History Museum of the Republic of Tatarstan, Russian Federation. Specimens were photographed in the laboratory.

The measuring of the best-preserved specimens was carried out. The different parameters of trace morphology and the different patterns were all recorded following standard procedural practice in invertebrate ichnology [1].

### Geological Setting

The East European Platform is a type region for the Permian system, considered as one of the largest Permian sedimentary basins in the world. Permian deposits cover stratigraphically, a continuous succession representing more than 45 Ma of Earth’s history. In the study area, these deposits are composed of series; completely marine deposits, marine and continental transitional successions and entire continental deposits. Marine-continental (transitional) formations are the most difficult to interpret in terms of palaeoenvironment, palaeoecology and palaeoclimate due to the lack of reliable stratigraphic (biotic and abiotic) markers for interregional correlations [2]. However, these formations cover a large part of the Eastern European Platform, with an important thickness.

The Volga and Kama River regions are part of the Russian Plate that belongs to the Eastern European Platform. The Permian deposits consist of three parts, subdivided into stratigraphic units of the Russian General Stratigraphic Scale (RGSS): (i) the completely marine succession (Cisuralian Series); (ii) marine-continental (transitional) succession represented by the Ufimian, Kazanian and Urzhumian stages; (iii) completely continental succession consisting of Severodvinian and Vyatkian stages. The Ufimian stage tentatively coincides with the uppermost part of the Kungurian Stage of the International Chronostratigraphic Chart (ICC) [3]. The Kazanian and Urzhumian stages are correlated with the Roadian and Wordian of the ICC respectively. The last two constitute the Biarmian Series (= Early and Middle Guadalupian of the ICC). The Severodvinian and Vyatkin stages represent the Tatarian Series of the RGSS, tentatively correlated with the Capitanian stage (= Late Guadalupian of ICC) and the Lopingian Series of the ICC. The Middle and Late Permian are well exposed in many outcrops due to the topography (up to 200 m) and ongoing mining activities. The reported invertebrate ichnofossil assemblages come from marine strata of the Early and Late Kazanian age that constitute the lower part of the Biarmian Series [3]. The distribution of invertebrate ichnoassemblage described here is different between the lower and upper stage in term of diversity and abundance. The Early Kazanian consists of grey to brownish alternative series of shale, limestone, marlstone and sandstone. Overlying it is yellowish to brownish, fine grained, gently laminated limestone and that represents the Late Kazanian. Both stages are characterized by the presence of a high degree of bioturbation, and the presence of shell pavement.

### Ichnological descriptions

*Lockeia (James, 1879)*

*Lockeia siliquaria* (James, 1879) (Fig. 1): Horizontal to sub-horizontal, symmetrical to asymmetrical, smooth walled, non-ornamented, almond-shaped, elongated burrows, which are
in some specimens tapered at both extremities, although a longitudinal faint crest may be present in some burrows. The burrows are mainly preserved in convex hyporelief within fine-grained sandstone. These structures of *Lockeia* are present in different sizes, measuring from 3 to 8 mm in width and from 7 to 11 mm in length; the thickness is ranging from 3 to 4 mm. The burrows are in some places somewhat irregularly attached to/overlying each other, locally expressed by a serial alignment of elongated burrows, linked by a horizontal trace which is referred to the crawling traces of bivalves. These match the diagnostic features of the ichnogenus *Lockeia*. Moreover, the main diagnostic features of the ichnospecies *Lockeia siliquaria* are the elongate to narrow stout, hypichnial almond-shape, and the smooth wall, sometimes tapering ends.

Fig. 1. Bivalve traces from the Lower and Upper Kazanian deposits of the Volga Region.

*Ar. Arenituba; Lo. Lockeia; Pr. Protovolgaria; Pt. Ptychoplasma*

**Oblongichnus (Bel Haouz et al., 2019)**

Oblongichnus *solodukhoi* (Bel Haouz et al., 2019): Simple, straight to slightly curved, unbranched, unornamented, smooth walled burrow, oriented in multiple directions (vertical, inclined and horizontal), sub rectangular to oblong in cross-section. It is characterised by a thick lining with internal and external very fine-grained mucous layers. Burrow fill is typically massive and similar to the host rock lithology. Overcrossings may be present. This ichnotaxon has been erected based on material coming from Seryi Kamen Member of the Upper Kazanian Stratotype Section [5].
**Protovirgularia (M’Coy, 1850)**

*Protovirgularia* cf. *dichotoma* (M’Coy, 1850): Horizontal, cylindrical, straight or slightly curved trapezoidal, unbranched, discontinuous keel-like burrows. These burrows are faintly bilobed with a faint median furrow, bilaterally symmetrical or asymmetrical. It is possible for narrow wedge-shaped appendages to be present. Some specimens are marked by almond-shaped traces in their terminations. The width of these burrows’ ranges from 5 to 10 mm, with a variable length measuring up to 10 cm. Chevron-like lamellar ornamentation is locally developed. It is reduced towards one of the extremities or disappears in the same traces.

**Ptychoplasma (Fenton et Fenton, 1937)**

*Ptychoplasma vagans* (Książkiewicz, 1977): Irregularly meandering to looping, discontinuous burrows consisting of aligned series of amygdaloidal to elongated mounds tapering at both terminations. They are horizontal and aligned to the bedding plane and are preserved in convex hypo relief. Individual burrows are elongated elliptically to the point of being almond-shaped, and measure from 5 to 10 mm in length and 4 to 6 mm in width. The total burrow length is about 10 cm. The median longitudinal ridge is faint or absent. These burrows are locally overcrossing other indistinct burrows.

**Arenituba (Chamberlain, 1971)**

*Arenituba* isp. (Chamberlain, 1971): Irregularly arranged, sometimes branched tubes radiating from a central tunnel burrow, single or bunched, straight, slightly curved, smooth to indistinctly ornamented, filled with the same material as the host rock. These traces are preserved in convex hypo relief. They are composed of 5 straight-to-slightly-curved tunnels that originate from a central point. However, there could be more indistinct tunnels of which we are not aware due to the bad preservation and the overcrossing burrows. The tunnels measure 6 to 10 mm in width with a variable length up to 5 cm, and are marked in their terminations by almond-shaped traces.

**Palaeoenvironmental and Behavioural Implications**

Bivalves are considered the main trace-makers of *Lockeia*, and different living and feeding strategies of bivalves may cause different morphologies of *Lockeia* [10]. *Lockeia* is referred to as the resting trace (cubichnion) of burrowing pelecypods and bivalves [11], [12]. However, the ichnogenus *Lockeia* is considered as a representative of the dwelling traces (domichnia) of suspension feeders, or of fugichnial responses to changes in the environmental conditions [13].

Isolated *Lockeia* is commonly interpreted as a bivalve resting trace most probably produced by an animal with a wedge-foot [12]. However, small crustaceans may have also produced such traces [14]. The almond-shaped hypichnial structure in the bedding plane and the V-shaped depression in the section is repeated in the nearby laminas of a bivalve resting trace [11]. Thus, the repetitions are caused when the organism has re-adjusted its position due to a change in conditions (change in oxygen conditions, rapid sediment accumulation, etc.) or to reach a new feeding location [15]. Variation in the morphology in part indicates differences in the expansion of the bivalve wedge foot during burrowing. The ichnogenus *Lockeia* is mostly produced by bivalves in various environments within shallow-marine settings [12]. It is dated from the late Cambrian/early Ordovician to the Pleistocene, paralleling the distribution of bivalves in space and time. *Lockeia* is a facies-crossing form and present in all marine and freshwater environments [16], [13].

*Oblongichnus* is variably oriented, lined and passively filled. These features might possibly be ascribed to combining feeding and domicichnion behaviours [5], and it could be also interpreted as a vertically oriented filter, or as horizontal surface-deposit-feeding of bivalves.
The most likely producers of *Oblongichnus solodukhoi* are elongate and ultra-elongate bivalves [5]. The only occurrence of this ichnotaxon is restricted to a shallow-marine setting. *Protovirgularia cf. dichotoma* is interpreted as locomotion behaviour (repichnia) produced by bivalves [12]. It represents the straight forward movement of the bivalves, moving horizontally, or slightly inclined, through the substrate by using its elongated cleft-foot by the push-and-pull technique [16]. *Protovirgularia* has been recorded from a wide range of depositional environments, from shallow to deep water, restricting their implication in the palaeoenvironmental interpretations.

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Conclusions

There are 4 main types of bivalve traces reported from the Lower and Upper Kazanian strata of the Volga Region: (1) resting or dwelling traces ascribed to the ichnogenus *Lockeia*, (2) vertically and horizontally oriented filter- or surface-deposit-feeding from a stationary position, referring to the ichnogenus *Oblongichnus*, (3) horizontal mobility reflecting grazing near the sediment-water interface, ascribed to the ichnogenenlus *Protovirgularia*, (4) and combined locomotion and resting traces recorded by the ichnogenus *Ptychoplasma*. The association of the ichnogenus *Arenituba* with the form burrows led us to think that this ichnogenus could be also be produced by bivalves. Thus, it is supported by the bivalve trace crossing or is linked to this trace. Locally, *Protovirgularia*, or even *Ptychoplasma* showed a transition passage in the tunnel burrows originated from the central point of the ichnogenus *Arenituba*.

The *Lockeia-Protovirgularia-Ptychoplasma* association co-occurring with *Arenituba* could be a piece of evidence that all these traces could be produced by bivalves. However, as the Lower and Upper Kazanian strata have yielded such abundant and diverse bivalve fauna, this was reported from the whole section, and preserved as moulds, casts and impressions. Together with bivalve traces this indicates that the palaeoecological conditions, including food, oxygen and ideal substrate consistency, were extremely conducive for the bivalve community. This co-occurrence of bivalve body and trace fossils from the section might support our hypothesis about the potential tracemakers of the described association of trace fossils including the ichnogenus *Arenituba*. Further exploration in the section for further evidences of body- and trace fossil association is recommended to refine the ichnological data and strengthen this hypothesis.

Acknowledgments

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Some Features of the Spiriferida (Brachiopoda) of the Sakhanian Horizon (Middle-Upper Famennian) of the South of Novaya Zemlya

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Abstract

The Famennian deposits in the south of Novaya Zemlya are represented by shallow-marine limestones and dolomitized limestones. The most numerous and developed group in these deposits are brachiopods, dominated by the Spiriferida and Rhynchonellida. The study of Spiriferida from the Sakhanian Horizon (upper part of Pa. triangularis Zone – lower part of Pa. marginifera Zone) from Cape Khaimin (southern coast of Novaya Zemlya) revealed that the taxonomic structure of this fauna is less diverse than in the Frasnian, particularly for higher taxa (superfamilies, families). The assemblage includes one genus that survived the Frasnian/Famennian extinction – Cyrtospirifer Nalivkin and one Famennian genus – Dmitria Sidyachenko. In total, only three species are found in these sediments: Cyrtospirifer brodi (Wenjukow), C. sp. and Dmitria subrotunda Tcherk.

Keywords: Spiriferida, Upper Devonian, Famennian, Arctic, Novaya Zemlya

Introduction

Famennian spiriferids of Novaya Zemlya were first studied by D.V. Nalivkin in the 1930s. The complete work remained unpublished, but some of the results were included in later publications [1]. He described several Famennian species including a new one, and identified two stratigraphic levels with different brachiopods. S.V. Cherkesova identified spiriferids for geological surveys and stratigraphic studies from the 1950s to the 2000s. She gave a definition of spiriferids, and listed them in a number of major encyclopedic publications on the geology and stratigraphy of the Soviet Union [2]; [3] and in articles on the stratigraphy of the Devonian of Novaya Zemlya [4], [5]. In 1966, she first described the species Dmitria subrotunda Tcherk from the Sakhanian Horizon [6]. She offered several different versions of zonation using Spiriferida and Rhynchonellida in various publications. In the 2000s, S. V. Cherkesova made a detailed study of Rhynchonellida from the Famennian of Novaya Zemlya, allowing her to more fully characterize these deposits using Rhynchonellida than had been done using Spiriferida.

Famennian spiriferids of Novaya Zemlya need to be re-studied, and the first findings are presented here.

Material

The spiriferids under study were collected by M.A. Kuzmin in 1963, from a few Upper Devonian sections along the coastline of the Karskie Vorota Strait. He also completed a detailed bed-by-bed description of the sections. Later, S.V. Cherkesova selected rhynchonellids from this collection for study. A collection which she passed to me consists largely of spiriferids and contains very few productids. Spiriferids are represented by molds with the remains of the shell...
layer and, less often, by whole shells. The preservation allows the shape of the shell, the internal structure and the ribbing character to be studied, although in some cases the loss of the shell matrix makes it difficult to study elements such as cardinal angles, auricula, and interarea edges.

Unfortunately, the preservation of the surface very rarely allows study of the micro-ornamentation, which is one of the most important diagnostic characters.

**Geological Setting**

The Famennian deposits are well exposed along the western and eastern coasts of Novaya Zemlya and in its southern part. Relatively shallow marine carbonate sediments containing brachiopod fauna are distributed along the west coast and on the southern margin. They are composed mainly of dolomitized limestone and dolomite with a relatively impoverished fauna of brachiopods, cephalopods and gastropods. They lie conformably without a clear boundary on the Frasnian limestones, and are overlain by Carboniferous limestones. The Famennian of Novaya Zemlya includes the uppermost beds of the Menshikovian Horizon (lower part of *Pa. triangularis* zone), the Sakhanian Horizon (upper part of *Pa. triangularis* – lower part of *Pa. marginifera* zone) and the Kharlovian Horizon (upper part of *Pa. marginifera* – *Siph. praesulcata* zone). They are slightly different lithologically, and can be separated using fossils.

In the area of distribution of shallow marine carbonate sediments, the total thickness of the Famennian can exceed 700 meters. [4]

The Sakhanian Horizon corresponds to the *Dmitria subrotunda* – *Cyrtospirifer “archiaci”* brachiopod zone. In later papers [4], S.V. Cherkesova recognized the *Dmitria subrotunda* Subzone at the top of the Sakhanian Horizon. According to the studies mentioned above, the Sakhanian Horizon contains *Cyrtospirifer asiaticus* Brice, *Cyrtospirifer brodi* (Wenjukow), *Cyrtospirifer aff. lebedianicus* Nal., *Dmitria subrotunda* Tcherk. and *Cyrtiopsis* sp. The Kharlovian Horizon corresponds to the *Tarandrospirifer tarandrus* – “Ziganía” *ursa* brachiopod zone and contains *Tarandrospirifer tarandrus* (Nal.) and *Cyrtospirifer barumensis* (Sow).

Along the coastline of Karškie Vorota Strait (Fig. 1) sections with Famennian deposits are known near Cape Menshikov, Cape Khaimin and Cape Zhandr (although the last one also comprises the Frasnian/Famennian boundary). Sections near Cape Menshikovian and Cape Zhandr expose the lowermost part of the Famennian deposits, including the top layers of the Menshikovian Horizon and the base of the Sakhanian Horizon. They consist of gray dolomitized limestones with a thin black shale bed (30 cm thick) at the base of the Sakhanian Horizon. The limestones contain scanty spiriferids which are often strongly dolomitized.

![Fig. 1. Geographical position of the sections](image-url)
The larger section of the Sakhanian Horizon is located near Cape Khaimin. It is composed of dark gray and gray limestone with spotted dolomitization; lenses of black chert occur in the upper part of the section. Macrofossils are relatively rare and sometimes strongly recrystallized. Brachiopods are represented by Rhynchonellida, Spiriferida and less commonly by Productida. They mostly occur as single shells and valves, and there are different quantities in different beds, but only on two occasions do they form a coquina (5-20 cm thick) in the upper half of the section. Relatively numerous large gastropods and a few cephalopods are also found in these sediments. There are few beds consisting of stromatoporoids or algae, and some beds of limestone containing small algal colonies (10-20 cm in diameter). The number of fossils present, including brachiopods, as well as the size of the brachiopod shells, increases upwards in the section.

**Results and Discussions**

Among the studied spiriferids, Cyrtospiriferinae, represented by several species, predominate in the stratigraphic interval discussed. The predominant taxa are *Cyrtospirifer brodi* (Wenjukow) and *Cyrtospirifer* sp. The basal beds of the Sakhanian Horizon contain only the occasional specimens of *C. brodi* (Wenjukow). Most of the section contains both of these species. *Cyrtiopsinae Dmitria subrotunda* Tcherk. was found together with them in the upper part of the section near Cape Khaimin.

*Cyrtospirifer brodi* (Wenjukow) is widespread on the Russian Platform, the Urals and Central Asia. Many authors noted the similarity of this species with *C. asiaticus* Brice (= *Cyrtospirifer “archiaci”* Murch. before Brice’s revision of 1970 [7]). This similarity is especially pronounced between young individuals of *C. brodi* (Wenjukow) and adults of *C. asiaticus* Brice. S.V. Cherkesova [2], [3], [4] noted the presence of both *C. asiaticus* Brice (= *Cyrtospirifer “archiaci”* Murch.) and *C. brodi* (Wenjukow) in the Sakhanian Horizon, including the Cape Khaimin section. She also accepted this species as an index-species of the *Dmitria subrotunda – Cyrtospirifer “archiaci”* Zone for the whole area of shallow-marine Famennian deposits on Novaya Zemlya. However, the collection studied allows an assessment to be made of the variability of *C. brodi* (Wenjukow), which indicate that in the sections of the Karskie Vorota Strait, those with the least elongated shell can be treated as *C. asiaticus* Brice—although there is no reason to assume that they are two different species.

Some specimens of *Cyrtospirifer sp.* resemble *C. lebedianicus* Nal. (a species that is common on the Russian Platform and occasionally indicated by S.V. Cherkesova for the Northern regions of Novaya Zemlya). However, analysis of extensive and diverse material from Cape Khaimin showed that it is impossible to identify these specimens.

Both *Cyrtospirifer brodi* (Wenjukow) and *Cyrtospirifer* sp. are highly variable and therefore the final conclusion about the taxonomic composition of the Cyrtospiriferinae will require further research and may be hampered by the preservation of the shell layer (see under ‘Material’). At present, it is clear that among the Cyrtospiriferinae of the Sakhanian Horizon, three morphotypes emerged. They are associated with different ways of life, primarily with the mode of attachment to the substrate (Fig. 2).

The first morphotype is characterized by a relatively low and significantly curved ventral interarea and a not very elongated umbo. An ecological feature of these specimens is an inability to lean on the interarea when resting on the substrate. Thus, the attachment was mostly by the pedicle. This morphotype includes specimens of *C. brodi* (Wenjukow) with a low interarea and a relatively short umbo (resembling *C. asiaticus*, as mentioned above).

Typical *C. brodi* (Wenjukow) with their long umbo and high area should also be assigned to this morphotype because of the strongly curved area.
The second morphotype is characterized by a high, flat or weakly curved interarea clearly bounded, not a curved acute umbo and tiny auricula, which are very rarely preserved. These spiriferida can rest freely with the interarea lying on the substrate. This includes representatives of *Cyrtospirifer* sp. with a straight triangular interarea (*C. lebedianicus*-like).

The third morphotype is represented by spiriferids with very highly elongated umbo which may be straight or curved at the top. They are likely to represent shells of the brachiopod that formed banks. The curved umbos of some specimen’s support this. Some *Cyrtospirifer* sp., and less often *C. brodi* (Wenjukow), may have this appearance, along with other features of these species.

Fig. 2.1 – *Cyrtospirifer brodi* (Wenjukow), 443-3A-d/1, extreme specimens in the range of variability, resembling *C. asiaticus* Brice, the first morphotype in the present article, a – ventral valve, b – ventral interarea, c – lateral view; 2 – *Cyrtospirifer* sp., 443-3B-n/1, the second morphotype in the present article, a – ventral valve, b – ventral interarea, c – lateral view; 3 – *Cyrtospirifer* sp., 443-3E-t/1, the third morphotype in the present paper, a – ventral valve, b – ventral interarea, c – lateral view.

Conclusions

In general, the fauna of the Sakhanian Horizon is impoverished compared to the Frasnian fauna. Compared with the upper Frasnian, this is expressed not so much in the number of species, as in higher taxa. The Upper Frasnian spiriferids of Novaya Zemlya were represented by three superfamilies: Adolfioidea, Theodossioidea and Cyrtospiriferoidea, while the assemblage of the Sakhanian Horizon includes representatives of only one family, Cyrtospiriferidae. At the very beginning of the Famennian, only rare representatives of the genus *Cyrtospirifer* Nalivkin occurred here; as in some other regions, they were among the only
survivors of the Upper Kellwasser event. Later, the basin was inhabited by new species and genera (*Dmitria* Sidiachenko in the Sakhanian Horizon and *Tarandospirifer* Simakov in the Kharlovian Horizon), the number of individuals increased, but the level of biodiversity did not return to the level characteristic of the Frasnian fauna.

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Recumbent Folds of the Northern Periphery of the Balygychan Block (North eastern Russia): Local Phenomenon or General Patterns During Collision Process?

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Abstract

The widespread development of recumbent folds is established for the first time on the northwestern periphery of the Balygychan Block (North eastern Russia). However, the question remains unresolved whether this phenomenon is local or reflects the general patterns of dislocation formations at the junction of the Balygychan Block and the Inyali-Debin Synclinorium during collision processes.

Keywords: recumbent folds, Balygychan Block, Inyali-Debin Synclinorium, collision processes, North eastern Russia

Introduction

The Balygychan Block is a large tectonic element of Mesozoids of the Yana-Kolyma folded system in North eastern Russia. The outline of the Balygychan Block is of an angular isometric shape, mainly due to the tectonic structure of its borders (Fig. 1). The block’s structure includes the Middle and Upper Permian, Triassic, and Jurassic rocks, which in composition, to a certain extent, are close to deposits of the Verkhoyansk complex of the passive margin of the North Asian Craton, but were formed in a completely different geodynamic setting, due to the connection we have reconstructed with the Okhotsk-Taigonom volcanic arc [1], [2], [3], [4], [5], [6], [7].

The Balygychan Block is characterized by a calm slightly positive gravity field, affected by local anomalies of various signs and orders. Negative anomalies indicate the location of large granitoid bodies, including intrusive rock unexposed by erosion. Systems of terrigenous sediments, characterized by higher bulk density, are notable for positive gravity anomalies.

The structure of the magnetic field of the Balygychan Block is determined by the presence of rare mosaically located local linear and arcuate non-stretched anomalies complicated against the background of a calm magnetic field. The intensity of anomalies is low, their orientation is mainly north-western. The sites of development of sedimentary rocks correspond to alternating-sign mosaic anomalies, associated with hydrothermal contact-metasomatically altered rocks, which accompany intrusions of mostly acidic composition, including those unexposed by erosion [8].

The Balygychan Block is structurally related to the so-called areas of low-angle dislocations [9], [10]. The rocks are mainly crumpled into low-angle brachymorphic folds and often fractured by faults of various types. Sometimes, especially near zones of large disturbances, near-fault folds and thrust are observed. The width of the first-order folds is 5 to 15 km and their length are 30 to 50 km. The limbs of the folds are inclined at 20-60° and complicated with small-size folds, and in some places also with steep flexure bends. Folds of higher orders are
0.3-2 km wide, 5-10 km long, and their amplitude is 0.2-1 km. Straight symmetrical folds are more typical of the core parts of large folded formations, and the angle of inclination of their limbs complicated complicated is 20-50°. The limbs typically have asymmetrical compressed folds of smaller size, whose axial planes are parallel to the axial plane of the main fold of the large folded formations. The inclination angles of the limbs of small-size folds vary within 40-80° [12], [13].

**Fig. 1.** Fragment of the geological map [11] of the junction of the Balygychan Block and Inyali-Debin Synclinorium, including the work site location

**Materials and Methods**

In 2007-2018, we carried out field observations in the course of training geological mapping at a training site located at the upper reaches of the Pautovaya River (see Fig. 1). We used traditional methods of detailed geological mapping, and also did multiple measurements of bedding elements and faults. When revealing the folds, we made a detailed description of them and measured the orientation of all the elements of the folds in space.

**Results and Discussion**

As a result, we found that near the northern boundary of the Balygychan block, which for the most part coincides with the zone of large latitudinal discontinuous displacements, usually defined as the Pautovsky Fault, the nature of folded dislocations is complicated profoundly different from those described above.

In this place, on an area of about 15 km² in a strip 3 km wide, where the nature of exposure allowed, we documented numerous platy cylindrical recumbent folds with an amplitude of around ten meters in the rocks of the Upper Permian (Yava Series = Ovodovskaya Formation)
and the Lower Triassic (the Gerba and Laryukovaya Formations). Folds of identical morphology were observed in all outcrops, the dimensions of which made it possible to see both the hinge and the limbs of the fold at the same time, which suggests profound changes of the layered rock masses in this zone with the folds of this type. The folds were observed both in the rock-defended terraces of the watercourses and in the buttes on the watershed along the right side of the Pautovaya River’s valley (the excess above the Pautovaya River’s valley is around 400 m) (Fig. 2). Thus, the vertical range of changes in the layered rock masses with such folds is no less than 300-400 m.

As a rule, we observed in the outcrops a two-dimensional pattern of the section of structural formations by the outcrop plane, which gives only an approximate idea of the orientation of fold hinges. But at the mouth of Obryvistyi Creek (the left tributary of the Pautovaya River), the outcrop makes it possible to see a ten-meter long hinge of the platy cylindrical recumbent fold in the rocks of the Gerba Formation of the Lower Triassic. The hinge is oriented sub-horizontally slightly (10°) plunging southeast (130°). The thickness of the bed forming this fold is about 5 m. The visible amplitude is about 10 meters.

The northern part of the Balygychan Block under study, directly adjacent to the Pautovsky Fault, has unique geophysical features that distinguish it from the rest of the territory. There is a local negative gravity anomaly, which indicates the unexposed part of the Pautovsky Granitoid Rock Mass against the background of a calm positive field, which corresponds to the presence of sedimentary complex rocks. Here, positive magnetic strip anomalies of high intensity of sub-latitudinal extension prevail in the magnetic field structure. They are associated with pyrrhotite mineralization, which is caused by metamorphic hydrothermal processes in the areas of increased fracture density.

The question arises: What is the nature and regional scale of the extension of the described structural forms within the entire Balygychan Block? (This also indirectly questions its tectonic integrity, since there is an opinion in favour of the independence of the northern part of the Balygychan Block, which is sometimes considered as the Gerba Ledge). It is possible that the described structures were associated with collision processes during the interaction of the Balygychan block and the Inyali-Debin Synclinorium.

It should be noted that many previous researchers have repeatedly pointed out the complex nature of the relationship between the Balygychan Block and the Inyali-Debin Synclinorium, which includes the territory under study. For example, B. Mal’kov [14] documented here the “Pripautovsky System of Scaly Structure Faults.” On a map of 1:1,000,000 scale [12] a system of large overthrusts is also shown. V. Kuznetsov [13] noted that “a tectonic cover overlapping the structures of the Inyali-Debin Synclinorium is detected along the northern periphery of the Balygychan Uplift”. Finally, the last major monograph on the tectonics of Northeast Asia [15] stated that “the Pautovsky Fault … morphologically is a major overthrust with the dip of the fault directed south.”

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Fig. 2. Recumbent folds in the Upper Permian and Lower Triassic rocks at the Pautovaya River (the northern periphery of the Balygychan Block): a – laminated packages of recumbent folds on the right bank of the Pautovaya River; b – a fragment of the system of recumbent folds in the rocks of the Laryukovaya Formation, same place; c – the same, in the rocks of the Ovodovskaya Formation (= Yava Series), at the Obryvisti Creek.
On the map of geophysical data classification, the Pautovsky Fault is marked by the borders of classes with contrasting gravity-magnetic parameters. In geoelectric section, the Pautovsky fault is shown dipping south [16]. It is accompanied by smaller listric faults usually dipping south.

Nevertheless, the indicated sources do not contain specific factual data clearly illustrating the complexes described; therefore, this publication is essentially the first study (not including brief abstracts of regional meeting reports that we have published earlier), which provides specific field materials testifying to the extensive development of complicated complexes in the northern part of the Balygychan Block.

Conclusions

Thus, the information obtained from our examination of the extensive distribution of the complexly dislocated complexes, once again questions the traditional interpretation of the Balygychan Block (Uplift) as a region of development of low-angle dislocations, and imply that its structure and formation history are much more complex, and are typical of the development of collision zones.

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On the Global Biogeography of Permian Marine Bivalve Mollusks

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Abstract

The main features of the global biogeography of Permian marine bivalve mollusks are considered. Three biochores of a high rank are distinctly distinguished – the Boreal, Tethyan, and Gondwanan (Notal) Superrealms. In the Tethyan Superrealm, endemism at the family level is widely manifested. Many groups of bivalves that are absent in the basins of temperate latitudes are characteristic – posidoniids, entoliids, annuliconchids, isognomoniids, ostreids, alatoconchids, etc. In the Boreal Superrealm, only one endemic subfamily Kolymiinae is present. Representatives of this family dominate in the eastern part of the Superrealm, making it possible to establish the Eastern Boreal Realm. Here, a large proportion of genera also have a bipolar distribution. The West Boreal Realm is primarily distinguished by the wide development of pterioids, myalinids, mytilides, \textit{Pseudomonotis, Cyrtorostra, Netschajewia}.

Euridesmidae and Permoceramidae are specific to the Gondwanan Superrealm; there are several endemic subfamilies of pectinoids. The bipolarity phenomenon is as widely manifested as in the Boreal Superrealm.

Keywords: paleobiogeography, marine bivalves, Permian

Introduction

The Permian period was the time when differentiation of marine faunas was most vividly manifested. To a certain extent, this is explained by a cooling of the climate (especially in the Early Permian), but, more obviously, to a greater extent, by the geocratic character of the Permian, manifested in the appearance of numerous biogeographic barriers during of the formation of the supercontinent Pangea-2.

Marine bivalves are one of the most widespread groups of the Permian biota, particularly in high latitude Boreal marine basins, where Permian communities are frequently dominated by bivalves [1]. In this area, bivalve species diversity is often greater than that of all other faunal groups. In the Permian, for the first time in the geological history of the Earth, the phenomenon of bipolar (antitropy) distribution of taxa in almost all biota groups was clearly manifested [2]. Bivalves also very clearly illustrate this phenomenon.

Results and Discussion

At present, it is generally accepted that the highest unit of biogeographical zonation is the superrealm [3], [4], [5], [1], [6]). In the Permian, almost all researchers recognize the existence of three large high-ranking biochores: The Boreal, Tethyan (Paleoequatorial), and Gondwanan (Notal), which we also consider at the rank of superrealms (Fig. 1).
Fig. 1. Biogeographical zonation of the world’s Permian marine basins by bivalve mollusks. Paleogeographic framework after [7].


The aim of this work is to consider in general features the Permian global biogeography based on marine bivalve mollusks. For the Boreal Superrealm such more detailed biogeographic zonation has already been done by the author earlier [6].
**Bivalve biogeographical zonation of Permian marine basins of the World**

**The Boreal Superrealm.** Boreal bivalve communities are primarily distinguished by a relatively low taxonomic diversity of at most family or even subfamily rank [8], [9], [10], [1], [11], etc.). Kolyminae is the only endemic Boreal bivalve subfamily, and is dominant in many basins of the eastern part of the Boreal Superrealm – the Eastern (High latitude) Boreal Realm (Verkhoyansk, Kolyma-Omolon-Chukotka region, Taimyr, Novaya Zemlya, Transbaikalia, central and northern Mongolia). Many pectinoid taxa (posidonidids, entoliids, annuliconchids, etc.) are completely absent here. Pterinopectinids, carditids, and lucinids are limited in distribution. Nuculids often play a significant role in communities. The proportion of the genera with bipolar distribution is high, particularly *Merismopteria*, *Undopecten*, *Myophossa*, *Cosmomya*, *Praeundulomya*, *Vacunella*, *Myonia*, *Megadesmus*, *Pyramus*, and *Stutchburia*.

In contrast to the basins of the Tethyan Superrealm, in some Boreal basins (in particular, northeastern Asiatic), bivalves are one of the main benthic groups, represented by abundant specimens and sometimes playing a rock-building role.

The Western (Low latitude) Boreal Realm includes the basins of England, the Baltic countries, Poland, the north of the Russian Plate (including the Kanin Peninsula), the Pechora basin, the Urals, the Volga Region, Spitsbergen, Greenland, and the Canadian Arctic Archipelago.

This realm is distinguished primarily by the widespread development of pteroids, myalinids, mytilides, *Pseudomonotis*, *Cyrtorostra*, *Netschajewia*. The latter are especially characteristic of the Western Boreal Realm and can be considered as indicative. In some places in the Western Boreal basins (Greenland, Spitsbergen, Pechora basin, Kanin Peninsula), rare *Inoceramus*-like taxa (*Evenia*, *Maitaia*, *Costatoaphanaia*, *Aphanaia*) are also noted. In the Western Boreal region, the number of bipolar taxa among bivalves is much smaller than in the Eastern Boreal.

**The Tethyan Superrealm** includes the basins of southern Mongolia, Primorye, Koryakia, Japan, North America (except for Yukon and the Canadian Arctic Archipelago), the Mediterranean, northern Caucasus, Iran, Pamir, Indochina, South China, and Malaysia and is characterized by an exclusively rich taxonomic composition of bivalves [12], [13], [14], [15], [16], [17], [18], [19], etc.). It displays well pronounced endemism at the family level. Many bivalve groups absent in the basins of moderate latitudes, such as pterinopectinids, posidoniods, entoliids, annuliconchids, isognomoniods, ostreids, alatoconchids, and others, are characteristic of this area. Paralledontids, bakewellids, myalinids, pterineids, various pectinoid groups, *Schizodus*, and some related genera are rather frequent.

It is interesting that Permian bivalve communities of North America (Midcontinent Basin) are in many respects similar to Western Boreal communities, differing only in the greater faunal diversity (particularly among pectinoids) and the presence of some specific index Tethyan genera (*Pterinopectinella*, *Pernopecten*, *Annuliconcha*, *Leptochondria*, *Goniophora*, *Costatoria*, *Gryphellina*) [20], [13], [15], [18]. At the same time, both types of communities include many *Myalina*, *Bakewellia*, pterineids, and *Permophorus*.

Note that bivalves are usually a minor element of benthic Tethyan communities, which are distinctly inferior in number to brachiopods and some other groups [21].

**Gondwanan Superrealm** includes marine basins of South America (Argentina and Brazil), South Africa, Hindustan, Tibet, Oceania (Timor and New Caledonia), Antarctica, Western and Eastern Australia, and New Zealand. Bivalve communities, as in the Boreal Superrealm, show a rather low taxonomic diversity [22], [23], [24], [25], [26], [27], [28], etc.). The presence in the Early Permian of the endemic family Euridesmidae and in the Middle Permian of the subfamily Permoceraminae are the most remarkable features. There are also several endemic pectinoid subfamilies recently established by Waterhouse [24], [29]. Another characteristic feature is the presence of *Inoceramus*-like bivalves of the subfamily Atomodesmatinae; bipolarity is rather typical (at the level of genera and even some species). In the Parana Basin
(Brazilian Province), there are specific brackish-water bivalves, including several endemic genera and the endemic subfamily Pinzonellinae [30].

It is interesting to note that the Permian marine bivalve faunas of Argentina show similarity with the boreal fauna only at the generic level, with almost complete absence of related species [31].

Conclusions

The conducted studies make it possible to confidently distinguish three biochoria of high rank for Permian biota of the marine basins of the world – Boreal, Tethyan, and Gondwanan (Notal) Superrealms. Each of these is characterized by its specific composition of bivalve communities and endemics at the family or subfamily level. This is especially characteristic for the Tethyan Superrealm, where endemism at the family level is widespread. However, in Tethyan communities, bivalve mollusks play a secondary role. A characteristic feature of the eastern part of the Boreal Superrealm is the dominance of bivalves in benthic communities. The Boreal and Gondwanan Superrealms are characterized by the wide distribution of bipolar taxa.

This phenomenon was for the first time so clearly manifested in the geological history of the Earth in the Permian.

Acknowledgments

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Geochemical Characteristics of the Middle Permian “Kolymic” Limestones of the Omolon Massif

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Abstract

The paper discusses new data on the geochemistry of the Roadian-Wordian “kolymic” limestones in the south-eastern part of the Omolon Basin: small element concentrations, and redox indicators. It is assumed that these rocks were formed in a shallow, oxygenated environment, in the immediate vicinity of a volcanic arc.

Keywords: Permian, “kolymic” limestone, Omolon Massif, geochemistry, sedimentary environments

Introduction

Currently, the use of small elements to interpret the conditions for the formation of carbonate rocks (e.g., [1], [2]) has met with some success. In this article, we also attempted to interpret the data small element concentrations for the middle Permian Roadian-Wordian carbonate rocks of the southeastern part of the Omolon Massif, the age of the deposits was adopted according to (e.g., [3], [4]). The problems of elucidating their formation conditions are quite relevant for these limestones, and one way to resolve these issues lies in geochemical studies of limestone.

The rocks we studied are called “kolymic” limestones, and are described in detail in the same collection book in the article “New data on the “kolymic” limestones of the Omolon Massif” [5].

Research Methods

The work is based on original material obtained as a result of the study of small element concentrations of two coeval sections along the Russkaya-Omolonskaya River and the Vodopadnyi Creek of the south-eastern part of the Omolon Massif [5]. The material, 20 samples, was collected during the 2014-2015 field seasons. The chemical composition of the Middle Permian carbonate deposits was studied using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at the Federal State Budgetary Institution “A. P. Karpinsky Russian Geological Research Institute” (St. Petersburg) and the Institute of Tectonics and Geophysics Far Eastern Branch Russian Academy of Science (Khabarovsk).

We used fairly well-known methods and indicators proposed to interpret the chemical composition of limestones (e.g., [1], [6], [7]).

Results and Discussion

The amount of small element concentrations in the sections of the Russkaya-Omolonskaya River (Table 1) ranges from 11.38 to 24.22 g/t, and along the Vodopadnyi Creek (Table 2) from 26.63 to 91.47 g/t; such a small element concentrations content is proportional to the amount
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of terrigenous material in these sections according to our petrographic observations and analysis
of the insoluble residue content [8].
Table 1. Small element concentrations in “kolymic” limestones in the Russkaya – Omolonskaya section
63-6
64-1
64-4
64-7
64-8
64-10
64-12
64-17
67-2
67-4
7.55
4.11
2.68
1.78
3.64
6.11
1.86
4.03
4.09
4.49
0.11
0.09
0.09
0.09
0.05
0.13
0.11
0.04
0.08
0.04
1.45
0.76
1.17
0.67
0.10
1.09
0.53
<0.001
0.21
0.37
13.88
9.20
11.63
9.01
3.29
15.69
5.05
2.02
7.01
6.35
5.97
8.29
8.27
8.20
3.85
10.06
7.06
1.90
4.04
1.92
2.22
1.00
1.35
1.26
0.64
1.05
0.80
0.90
1.04
0.91
2.70
7.09
7.05
5.84
3.70
5.12
3.50
4.49
3.04
2.48
11.26
5.08
4.94
2.34
<0.001 <0.001
<0.001
<0.001
<0.001
0.34
2646.43 4.17
0.35
<0.001
<0.001 <0.001
<0.001
<0.001
<0.001
<0.001
1.58
1.18
1.44
0.85
0.38
1.11
0.76
0.27
0.75
0.52
0.23
0.29
0.15
0.09
0.06
0.14
0.07
0.08
0.21
0.19
4.74
<0.001 0.64
1.41
0.35
1.08
1.59
1.10
0.12
<0.001
3.61
5.64
8.77
6.02
3.30
5.75
3.37
1.64
2.49
1.58
3584.20 720.62 452.25
435.04
361.92 349.04
376.24
418.40
502.78
965.56
6.29
5.21
4.52
8.10
3.79
4.47
3.25
2.58
4.14
4.34
93.65
9.92
9.48
8.17
13.99
5.98
5.89
3.25
7.94
5.21
1.43
0.83
1.02
0.74
0.04
0.27
0.22
<0.001
0.09
0.05
1.88
0.42
0.48
0.46
0.14
0.42
0.21
0.51
1.12
0.53
0.11
0.49
0.12
0.32
<0.001 0.03
0.12
<0.001
<0.001
1.06
0.29
0.05
0.10
0.13
0.06
0.06
0.08
0.03
0.07
0.03
0.24
0.33
0.54
0.29
0.14
0.21
0.13
0.08
0.16
0.11
84561.3 262.36 108.82
48.78
26.71
51.07
13.99
4.93
211.12
244.63
4.98
5.09
4.76
7.75
4.25
6.85
5.20
3.33
2.64
3.23
8.14
5.75
5.42
6.91
2.81
5.66
4.25
2.84
3.38
3.56
1.02
1.00
1.01
1.49
0.73
1.36
1.04
0.61
0.50
0.59
3.85
3.84
3.89
5.87
2.91
5.19
3.81
2.37
2.03
2.40
1.22
0.78
0.77
1.14
0.56
0.99
0.72
0.45
0.42
0.50
0.53
0.19
0.19
0.28
0.14
0.23
0.16
0.10
0.11
0.14
0.99
0.95
0.89
1.43
0.69
1.11
0.80
0.51
0.54
0.65
0.17
0.14
0.13
0.21
0.10
0.16
0.11
0.07
0.09
0.10
1.04
0.74
0.73
1.13
0.54
0.81
0.58
0.38
0.54
0.61
0.24
0.16
0.15
0.24
0.11
0.16
0.11
0.08
0.13
0.14
0.76
0.43
0.41
0.64
0.29
0.41
0.29
0.22
0.41
0.43
0.14
0.06
0.06
0.09
0.039
0.056
0.039
0.032
0.068
0.069
0.98
0.38
0.39
0.51
0.24
0.34
0.24
0.21
0.46
0.48
0.16
0.06
0.06
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0.036
0.051
0.036
0.035
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0.080
2.12
0.22
0.23
0.16
0.33
0.18
0.18
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0.16
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6.42
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<0.001
<0.001
1.13
0.22
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0.57
<0.001
0.16
1.56
0.40
0.25
0.52
0.13
0.13
0.27
0.29
0.08
0.19
0.14
0.21
0.36
0.36
1.22
0.17
0.26
0.16
0.07
0.85
0.17

Li
Be
Sc
V
Cr
Co
Ni
Cu
Zn
Ga
Ge
As
Rb
Sr
Y
Zr
Nb
Mo
Sn
Sb
Cs
Ba
La
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Hf
Ta
W
Pb
Th
U
Ce
anom
Σ
РЗЭ
V/Cr
V/(V
+Ni)
U аut

0.89

0.63

0.64

0.52

0.43

0.45

0.42

0.50

0.84

0.80

24.22

19.56

18.86

27.75

13.44

23.38

17.41

11.24

11.38

12.97

2.32

1.11

1.41

1.10

0.86

1.56

0.72

1.062

1.732

3.31

0.84

0.56

0.627

0.61

0.47

0.75

0.59

0.31

0.70

0.72

0.08

0.28

0.19

1.18

0.13

0.17

0.06

0.04

0.79

0.13

The concentrations of elements, such as Cr, V, Ni, Co, Cu, Pb, Sn, Zn, Be, Y, Nb, Rb, Sc,
which are typical for insoluble residue (terrigenous admixture), usually reflect the composition
46


of the feeding province [1], and elements such as Sr and Ba are associated with a carbonate substance. We compared the content of these elements in our limestones with their clarke values in carbonate rocks. According to the authors of the monograph [9], clarke values of elements in carbonate sediments represent the average content of elements in a certain sample of carbonate rocks, regardless of the geodynamic conditions of their formation. It is expected that an “average” rock will contain elements equally characteristic of magma rocks of various specializations (acidic, medium, basic, etc.). In the event of the absence of such rocks in the erosion area (or corresponding to the composition of the products of weathering and redeposition), the concentration of their characteristic elements in carbonates should be significantly lower than the clarke value. Conversely, if the source area, having a certain composition, was not sufficiently remote, the content of the corresponding small elements will be higher than the clarke value.

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<th>109-7</th>
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<th>119-2</th>
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“Kolymic” limestones are characterized by a slightly higher content (compared with clarke values), La, Ce, Nd, Eu, Dy, Yb, Sr, Li, Nb. The practical absence or lower content of clarke

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elements such as Cu, Zn, Ni, Cr indicates the absence of ultrabasic and basic rocks among the sources. A low content of Be and Sn indicates the absence of sources of acidic rocks. Hence, it can be assumed that although these sections are located close to each other, and despite their similar structure, carbonate deposits in the section along the Vodopadnyi Creek had a greater amount of terrigenous material than in the section of the Russkaya-Omolonskaya River. It was difficult to tell what the source of the runoff was, but we believe that rocks of medium composition were eroded, and the section along the Vodopadnyi Creek was closer to the source area.

In the modern geological literature, various methods are used as indicators of redox conditions for carbonate rocks. A significant place among them is taken by geochemical indicators, such as: V/Cr [6], V/(V+Ni) [10], and U-aut [7]. The ratio V/Cr, as well as V/(V+Ni), was calculated only for limestones of Russkaya-Omolonskaya River, and there is no data on Vodopadnyi Creek limestones. The V/Cr parameter ranges from 0.7 to 3.3, and V/(V+Ni) from 0.47 to 0.83, which corresponds to oxic and dysoxic conditions (e.g. [6], [10]). The ratio U-aut is in the range from 0.08 to 0.79 g/t for the rocks of the Russkaya-Omolonskaya River, and from -0.09 to 1.08 for Vodopadnyi Creek, which indicates an oxygen depositional environment.

Only one sample (119-3/AB-15) has a high value of 17.91, indicating an oxygen-free environment. The deep negative anomaly of Ce, calculated by us according to the formula proposed in [2], also indicates the presence of oxygen in the middle Permian time. Ce content in limestones of the Russkaya-Omolonskaya River is in the range from 0.42 to 0.89, and on the Vodopadnyi Creek from 0.43 to 0.91.

Sr content in limestones ranges from 349 to 3584 g/t (the Russkaya-Omolonskaya River) and from 215 to 670 g/t (the Vodopadnyi Creek) with a clarke value of 540 g/t [9]. The Ba content is from 5 to 84,561 g/t (the Russkaya-Omolonskaya River) and from 12 to 451 g/t (the Vodopadnyi Creek) with a clarke value of 53 g/t [9]. These values are high enough, and probably they were even higher; such high values of strontium can be explained by the relative elevation of the carbonate sedimentation region in comparison with the surrounding deep-water basins [11]. Another reason for such contents may be that the Omolon Basin from the paleotectonic point of view was at least partially a back-arc basin, and the high contents of Sr and Ba are explained by post-volcanic hydrothermal activity [1]. The lower-clad Zr content in the samples also supports adheres to this idea. The clarke content of zircon is 20 g/t [9], and our values are from 3.25 to 13.99 g/t, except for sample 63-6 / AB-14, where the content is higher than the clarke value.

Limestones formed in relatively shallow environments, as indicated by the presence of bioherm constructions, have fossil complexes characterized by extreme poverty of taxonomic composition [2], and a group of ichnofossils belonging to shallow ichnofacies [6]. At the end of the middle Omolonian time, transgression of the sea began, as evidenced by the growth of a negative Ce anomaly (Fig. 1), which is also confirmed by published data (e.g., [4], [10]).

The oxygenated conditions of the Omolon Basin, which are indicated by the values of the redox indicators used are not in conflict with the characteristic smell of hydrogen sulfide, characteristic of “kolymic” limestones. These deposits could form in an anaerobic diagenetic system with no contact with water. The abnormally high are Sr contents (from 452 to 3584 g/t) and Ba contents (from 109 to 84561 g/t) that we encountered in the top of this thin “kolymic” limestones near the with the overlying clay bed, may also indicate the closed nature of this late diagenetic system [12].
Fig 1. Variations of the redox indicator’s ratios for two sections of the Omolon Massif

Conclusions

Our studies suggest that the sedimentation conditions in the middle Permian in the Omolon Basin were mostly oxygenous. Our results differ from those of V.G. Ganelin who suggested that limestones formed in anoxic environments [13]. It should also be noted that the medium-sized terrigenous mixture most likely came from the Okhotsk-Taigonos volcanic arc, since the Omolon Basin was located quite far from the land [14], but for “pure” limestones, have quite a large amount of terrigenous admixture.

Acknowledgments

The authors are grateful to Dr. Sci. A.S. Biakov for advice on writing this article. Dr. Sci. V. M. Kuznetsov and D. I. Alekseev for providing data on the geochemistry of small elements (Russkaya-Omolonskaya R.). This work was partially supported by a grant from the Governor of the Magadan Region in 2019.

REFERENCES

New Data on the “Kolymic” Limestones of the Omolon Massif

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Abstract

Macro- and microscopic research was conducted on Permian “kolymic” limestones of the south-eastern part of the Omolon Massif. A brief history of the research into these deposits in the Omolon Massif is provided. “Kolymic” limestones are unique formations described from only a few tectonic structures in North-East Russia, Alaska and New Zealand.

Keywords: the Permian, “kolymic” limestone, Omolon Massif, history of study

Introduction

During the Late Paleozoic, and Permian in particular, carbonate accumulated sporadically only within some tectonic structures of North-East of Asia, i.e. the Omolon Massif, the Omulevskyi Block, and a number of areas of the Prikolyma [1]. In this article, we will consider the carbonate rocks of the Omolon Massif, which are commonly called “kolymic” limestones.

The Omolon Massif and its geodynamic position have been discussed in the geological literature for many decades (e.g., [2], [3]). From this point of view, it is of interest to determine the conditions for the formation of Permian strata, as well as to research “kolymic” limestones from the south-eastern part of the Omolon Massif (Fig. 1), along three sections of the Russkaya-Omolonskaya River, the Vodopadnyi Creek, and the Munugudzhak River.

“Kolymic” limestones [1] are carbonate rocks composed of randomly oriented thin calcite prisms less than 0.3 mm in size, with a hydrogen sulfide smell. These rocks are unique; similar formations are found only in Alaska [4] and New Zealand [5] where they are called “atomodesmic” limestones.

The mechanism of the formation of such rocks is quite controversial. There was almost no doubt for many years that the “kolymic” limestones are composed of disintegrated fragments of shells of Inoceramus-like bivalve mollusks, but a hypothesis of the bacterial origin of these rocks has appeared in the last decade (e.g., [6], [7]).

History of Study of “Kolymic” Limestones

The first information about “kolymic” limestones in the Omolon Massif was obtained by S.V. Obruchev, as a result of research in 1929-1930. In 1934, B.K. Likharev (who studied S.V. Obruchev’s paleontological collections) in his work “The Fauna of Permian Deposits of the Kolymic Territory” [8] pointed out the presence of at prismatic layer of Inoceramus-like bivalves of the Aphanaia genus in the limestone fragments.
Fig. 1. Locations of the studied sections (A): 1-Vodopadnyi Creek, 2 – Munugudzhak River, 3 – Russkaya-Omolskaya River and Regional stratigraphic scale and correlation of key Permian sections of the Omolon Massif and south-eastern part (e.g., [1], [14], [15], [16])(B): 1 – “kolymic” limestones; 2 – sandstones; 3 – siltstones; 4 – tuff admixture in rocks; 5 – tuff and tuffites; 6 – limestones lenses; 7 – diamictites; 8 – gravel and pebble-size material. ISS – International Stratigraphic Scale. RSS – Regional Stratigraphic Scale.
In O.V. Kirichenkov’s 1951 manuscript report “Upper Permian foraminifers of the Okhotsk-Kolymian Territory,” she assumed an algal origin for these limestones, which she called algal bioherm limestones. However, this point of view was soon abandoned.

In the 1980s, a group of specialists from St. Petersburg and Magadan carried out a comprehensive study of sections of the Permian deposits of the Omolon Massif on the Vodopadnyi Creek and the Russkaya-Omolonskaya River [9]. In this monograph [9], a detailed macro- and micro-description of “kolymic” limestones was made.

In 1999-2008, A.S. Biakov (e.g., [10], [11], [12]) believed that the limestone was formed by disintegration of shells of kolymiids, and to explain the mechanism itself, it was suggested that the prismatic layer of Kolymiidae shells has a special structure, where most of the material is organic, holds the shells together, and is easily disintegrated.

With the development of electron microscopy, V.G. Ganelin put forward a hypothesis of the bacterial origin of the “kolymic” limestones. He calls them carbonatolites [6]. To support this hypothesis, the author discussed in detail the morphology of prismatic “crusts” that do not resemble shells of *Inoceramus* like bivalves.

The formation of carbonatolites is associated with the life of certain hypothetical prokaryotes that fix marine carbonate, i.e. strict anaerobes, but facultative photo-chemoautolithotrophs (e.g., [7], [13]).

**Macro – and Microscopic Study of “Kolymic” Limestones**

“Kolymic” limestones can form separate layers from 1 cm to 2 meters thick and form entire strata more than 100 m thick. The oldest deposits that we studied are of middle Late Artinskian age (Fig. 1), and the youngest is of Wuchiapingian age (e.g., [17], [18], [19]).

Obviously, large geobiospheric events manifested during the Permian also could play a role in the stratigraphic distribution of this rock [20].

Limestones are gray, strong, siliceous, marl, massive or layered texture, their characteristic feature is a smell of hydrogen sulfide. They may contain thin inner layers of shell limestones or calcareous siltstones. In thin sections, the matrix is composed of disparate calcite prisms with sizes ranging from 0.02×0.2 mm to 0.05×0.7 mm, the predominant fraction is 0.05×0.3mm (Fig. 2A). Depending on the location in the section, they comprise up to 70 to 95% of the rock. Terrigenous admixture is represented by quartz, feldspar, plagioclase, less often chalcedony (Fig. 2B). The shape of these grains is idiomorphic, acute-angled; grain size is from 0.05 to 0.4mm. Terrigenous admixture constitutes from 1 to 15% of the rocks.

The cement of “kolymic” limestones is different: in the Rulon Formation it can be of chlorite-carbonate composition, pore type, and composes up to 5% of the rock; in the Dzhigdali Formation it is carbonate cement, pore type, and reaches up to 10%; in the Omolon Formation it has carbonate cement, film-pore type with a content in the rock of up to 5%; Khivach Formation has clay-chlorite-carbonate cement, of a basal-pore type, with a content of up to 15% in the rock.

We identified several subtypes besides typical “kolymic” limestones:
Fig. 2. Microphotographs showing “kolymic” limestones. A: the matrix is represented by differently oriented prisms; thin section 80-8/IB-14, the upper part of the Rulon Formation, Munugudzhak River; B: the terrigenous admixture in limestones; thin section 80-4/IB-14, middle part of the Rulon Formation, Munugudzhak River; C: the matrix composed of differently oriented prisms from the bioherm, thin section 109-9/IB-15, the middle part of the Omolon Formation, Pravyy Vodopadnyi Creek; D: the oolitic limestones, the matrix is represented by black prisms and oolites; thin section 126-1/IB-15, lower part of Omolon Formation, Vodopadnyi Creek.

On the Pravyi Vodopadnyi Creek, limestones of the Dzhigdali Formation have a visible thickness of two meters. Their distinctive characteristic is a lack of the smell of hydrogen sulfide. In these limestones, we found interlayers up to 3cm thick, saturated with opal (up to 85%), and there are single calcite prisms of “kolymic” limestones “floating” in them.

In the Levyi and Pravyi Vodopadnyi Creek sections there is a level of bioherms traced in the middle part of the Omolon Formation. We have established their concentric structure; the thickness of such buildups is from 0.5 to 7 meters. Body morphology is ellipsoidal, cigar-shaped, lenticular, the shape of curving lenses. The long axis is usually oriented subparallel to the bedding plane of the overlying limestone formations. It has been revealed and documented for the first time that the outer shell of the dark gray bioherm has a concentric structure similar to bacterial mats (Fig. 3B). Diffuse diagenetic pyrite is characteristic at this level. In thin sections, disparate calcite prisms of 0.02×0.2 mm in size are found (Fig. 2C), which comprise about 85% of the rock; terrigenous admixture comprises about one percent of the rock, represented by feldspars. The cement in these limestones is clayey, and occupies about 15% of the rock.
Fig. 3. “Kolymic” limestone from the Omolon formation, Vodopadnyi Creek. A: characteristic combination of the remains of peculiar bacterial structures of the “bubbly” appearance and the calcite “crust” of the prismatic structure surrounding them, similar to the prismatic layer of shells of *Inoceramus*-like bivalves; B: bacterial formations of a concentric structure in the outcrop wall, the contact of non-plastic “kolymic” limestones 18 m thick, contains abundant bioherms with reservoir limestones.

Also, we observed microbial structures (Fig. 3A) in the “kolymic” limestones of the Omolon Formation on the Vodopadnyi Creek surrounded by a typical prismatic layer that has nothing to do with the shape of shells of *Inoceramus*-like bivalve mollusks. The microbial isolation itself is surrounded by a calcareous crust, similar to the *Inoceramus*-like bivalve shell layer, and consists of calcite hexagonal columns closely oriented to each other, perpendicular to the crust surfaces.
The crust surrounding the microbial clot in the described section has a gap of about 1 cm long. Separate fragments (?) of the prismatic crust are visible in the inner part near the encircling crust. Such microbial isolations 15-20 cm in size are not common. “Bubble” microbial structures are mostly saturated with smaller (1-5 cm) segregations, also surrounded by calcite crusts, but they are thinner accordingly (0.5-1 mm). They are characterized by a peculiar twisting shape.

Another specific subtype of “kolymic” limestones is oolitic “kolymic” limestones, which was found in the talus deposits of the lower part of the Omolon Formation on the Vodopadnyi Creek. Limestones are of gray color, with hydrogen sulfide smell and an oolitic texture. The matrix is represented by differently oriented black prisms with a size of 0.05×0.1 mm; their black color may indicate a redistribution of organic matter in the rock. Oolites have a concentric structure, and comprise about 50% of the rock; the size of the prisms is 0.05×0.2 mm (Fig. 2D).

Oolites are of 3 mm in size and have a concentric structure: the outer part is composed of terrigenous impurities: quartz and feldspars, which are replaced by calcite, with a grain size up to 0.3 mm, the internal structure is homogeneous and contains neither terrigenous impurities nor prisms. Oolites compose up to 50% of the rock. The cement is of the film-type, and the rock contains less than 3% of this material.

Conclusions

“Kolymic” limestones of the south-eastern part of the Omolon Massif are divided into several types: “classic”; odorless hydrogen sulfide; oolitic; limestones from bioherm buildups; limestones from a microbial formation. The composition, size and shape of the terrigenous admixture suggest that during the formation of “kolymic” limestones, the source of material drift into the Permian basin did not change. The presence of microbial structures similar to the shape of shells of *Inoceramus*-like bivalve mollusks [12] indicates the bacterial formation of “kolymic” limestones. Currently, these enigmatic formations are still being studied using modern research techniques, for example, isotope studies of C, O and Sr; the study of samples under a scanning electron microscope, etc. All this research will help to reveal the genesis of “kolymic” limestones in the future.

Acknowledgments

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REFERENCES


On the Discoid Imprints Discovered in Novyi Kuvak (Middle Permian, Volga-Uralian Region)

BUKHMAN Nikolay

Abstract

The miniature discoid imprints discovered at the Novyi Kuvak site, which have a diameter of between 0.5 and 2 millimetres, are described. The different possible interpretations of what these imprints may be are discussed. One such interpretation is that they are the reproductive organs belonging to one of the plant groups discovered at this location.

Keywords: Permian flora, Lower Kazanian, Volga-Uralian Region, Rufloria, Peltaspermaceae, Tchernovia, Paracalamites

Introduction

Novyi Kuvak is one of the locations in the Volga-Uralian Region where Middle Permian (Kazanian) flora can be found [1], [2], [3], [4]. Geographically, this location is positioned in the extreme North-East of the Samara region, close to the border with Tatarstan. A more detailed description of the location is given by [5], [6], [7], [8], [9].

Most commonly found at this location are imprints of Cordaites foliage (Rufloria sp.). The next most frequently occurring imprints are those of the vegetative organs of plants from the Sphenophyta (Paracalamites sp.), Ginkgophyta and Peltaspermaceae. Imprints of seeds and peltoids with a common size and external appearance are rarely sampled. Two new species of peltoids have been described from the Novyi Kuvak site – Peltaspermopsis nebritovii [6] and Peltaspermum morovii [9].

Nevertheless, miniature discoid (or polygonal) imprints, which have diameters ranging from fractions of a millimeter to several millimeters, have been found here in massive numbers.

Externally they have an appearance similar to the seed-bearing discoids of the peltasperm species, or to the shield-like sporangiophores of the Tchernovia. Fig. 1-4 show photographs of how these imprints typically look, with Fig. 5 showing their more compact state.
Fig. 1. Photographs of the discoid imprints. Images a, b, c, d, e, f, g, h, i, m – sample no. 1-39; images j, k, l, n, o – sample no. 1-56. The length of the scale bar is 0.5 mm.
Fig. 2. Photographs of discoid imprints. All are from sample no. 1-59; see Fig. 5. The length of the scale bar is 1 mm.

Fig. 3. Photographs of discoid imprints. Images a, b, c, f, g, h is from sample no. 1-63; images d, e, i, j is from sample no. 1-56. The length of the scale bar is 0.2 mm.

Fig. 4. Photographs of discoid imprints. All are from sample no. 1-76. The length of the scale bar is 0.2 mm.
Methodology

The fossil plants found at the Novyi Kuvak site consist of calcareous fine-grained sandstone. As a result of this epidermal-cuticular analysis of the fossils is impossible. A microscopic examination of the surface of the bedding planes also turned out to be unsuccessful, primarily because when using a microscope, an increase in the magnification of the image results in a decrease of its depth of field, thus making it impossible to accurately display something with an uneven surface.

The main method of studying the samples was through an examination of their photographs, taken in macro mode so as to make it easy to see details which are a millimetre, or even a fraction of a millimetre, in size. Details of this size fall into the “dead zone” between macroscopic and microscopic examination, making them difficult to examine and thus poorly understood (though an examination of them can prove to be very informative).
Results

The discoid imprints on the surface of the bedding plane are sometimes isolated from each other (see Fig. 1-3), and at other times completely cover the entire surface of the bedding plane with irregular polygons (see Fig. 4, 5). On the isolated imprints of the adaxial surface it is possible to discern 6 to 8 scars, as well as an interesting and curious structure consisting of two concentric circles, the space between which is divided by a radial pattern of cylinders into trapezoidal areas (in the center of which are located the scars). This can be seen on Fig. 1 (a, b, c, d, i, m), Fig. 2 (d, e, f, m, o) and Fig. 3 (d, j). The number of festoons seems to correspond to the number of scars, which can either be straight (Fig. 1 (a)) or bent (Fig. 1 (e, g, h, j), Fig. 2 (l), Fig. 3 (i)). The upper surface of the discoid is slightly convex with a slight rounded elevation in the center (Fig. 1 (f), Fig. 2 (b, h)). Sometimes there are small drop-shaped objects either attached to the discoid (Fig. 1 (b, m, o)) or associated with them (Fig. 2 (a)). In shape (but not in size) they more closely resemble seeds rather than sporangia, but there is a possibility that they are neither.

All the mentioned samples are stored in the Paleontological Collection of the Department of Physics and Geology of Samara State Technical University.

Discussion

Due to the mode of preservation, it is impossible to accurately establish the systematic affiliation of the described fossils. Therefore, the author refrains both from comparing these imprints with the Peltaspermaceae seed discoids, as well as from comparing them with the peltate sporangiophores of the Tchernoviaceae. Nevertheless, it is possible that the described imprints are the remnants of the reproductive organs of one of the plant groups found in Novyi Kuvak.

Conclusions

The main result of the investigation is the conclusion that the peculiar and unclear discrepancy between the abundance of imprints of vegetative organs and the rarity of imprints of reproductive organs found in Novyi Kuvak is seemingly compensated by the large number of imprints of reproductive organs and seeds, both of an unusually small size.

REFERENCES

The First Discovery of Coccoliths in the Paleozoic Salts of the Solikamsk and Pripyat Tectonic Troughs

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Abstract

Fossil coccoliths were discovered in the insoluble remains of the Verkhnekamsk (Solikamsk depression) and Starobin (the Pripyat Trough) salt deposits. The study of salt layers with algae residues can considerably change the currently accepted limit of the coccolithophores age lower bound. The fact sea algae were found throughout the whole section of the saline series indicates that these deposits had a constant connection to the ocean.

Introduction

Despite the large number of halophilic microorganisms discovered, there is no record of calcareous algae being found in saline series, including in potassium salts and potassium-magnesium salts formed from the highest-mineralized brines (300-5000 g/dm³). The only record of coccolithophore discoveries in high-mineralized water refers to the Dead Sea. These discoveries are palmelloid cells [1] that develop in adverse environments and conditions. There are records of individual discoveries of coccoliths without an identified species in gypsum-dolomite Messinian Mediterranean sediments [2]. The normal development of coccolithophores is only possible in an alkaline environment (pH=8-8.5) with a salinity level of 5-45 g/dm³. In an acidic environment (pH <7) the cells pass to a palmeloid state.

It is believed that the evolution of calcareous nannofossils began in the Mesozoic, since the first reliable discoveries of fossil coccoliths were recorded in late Triassic sediments (Nori tier, 217-204 million years ago) [3]. Small, finely structured, multi-crystalline objects were found in more ancient Paleozoic sediments, but there is no clear interpretation as to what they were [4], [5], [6], [7], [8].

Thus, the probability of finding calcareous algae in such extreme, super-saline conditions, uncharacteristic of sediments older than the Triassic, is low. However, numerous discoveries of well-preserved coccoliths and coccolithophores have been recorded during the exploration of the insoluble salt residues of the Verkhnekamsk (Solikamsk depression) and Starobin (Pripyat trough) salt deposits, thus allowing us to identify their species. Therefore, the aim of our research was to assess the reliability of these discoveries and their role in helping understand the geological development of Paleozoic evaporite basins.

The Verkhnekamsk potassium and magnesium salt deposit is located in the Solikamsk trough, one of the tectonic structures of the Pre-Ural Foredemp, which emerged during the Ural fold’s encroachment on the structures of the East European platform. The deposition of evaporitic sediments took place over a large area of the platform. However, the accumulation of salt was controlled by the deepest basins (Caspian, Mrakovsk, Belsk, Jurujuano-Sylven, Solikamsk, Verhnepechorsk) located along the Urals (Fig. 1). These basins are separated from neighbouring structures by faults, while anticlinal folds separate them from each other. The flow of sea-water occurred mainly from the North [9]. The formed halogen series of the Solikamsk trough refers to the Irene Horizon of the Kungurian age of the lower Permian. It
includes deposits of underlying rock salt, potassium, and potassium-magnesium, as well as a coating of rock salt (Fig. 2). The brines coexisting with salts are characterized by an acidic consistency (pH 4.7-6.9), high mineralization (378-418 g/dm³), and by the mixture’s evolution upward along the saline formation from sodium chloride to magnesium (or calcium) chloride.

**Fig. 1.** Paleogeographic maps of the Kungurian (a) and the Famennian (b) age (according to Zharkov, 1984, as amended): 1 – contour of the sea basin; 2 – direction of ocean water inflow; 3 – tectonic boundaries determining the configuration of basins with evaporitic sedimentation. The numbers indicate the deflections with potash salt deposits: I – Caspian; II – Solikamsky; III – Verkhnepechora; IV – Pripyat.

The Starobin salt deposit is located in the north west part of the Pripyat Trough which extends north from the Dnepr-Donetsk Basin. During the period between the late Frasnian until the early Permian it was developing as a fault trough. It is thought that during the crystallization of potassium salt in the Middle Famennian stage of the Late Devonian epoch the salt basin was shallow. The inflow of sea water was thought to come mainly from the Dnieper-Donets Basin [9], [10]. The brines coexisting with the salts are characterized by their acidic consistency (pH 4.5-7), high mineralization (310-496 g/dm³) and the evolution of the whole mixture from calcium chloride to potassium chloride due to the degassing of inner magmatic outflows during the process of the rift structure’s formation [11].

A large number of carbonized remains of large merostomes (Eurypterida) have been found in the saline series. These series refer to the argillous layers of the third potassium horizon [12] with 7 sylvinitic or carnallite layers. These Eurypterids are typically marine, but there are signs indicating that they could have been present in fresh water, freshened lagoons, or in the estuaries of rivers.

Thus, the described troughs can vary considerably in their tectonic nature and in the evolution of their brine composition.
Methodology

The original purpose of the test was to study the mineral composition of the insoluble salt residue found in the Starobin and Verkhnekamsk salt deposits. The materials for the study were collected with the help of a drilling machine with a cylindrical casing head reinforced with tungsten carbide. This equipment made it possible to drill samples with a diameter of 8 centimetres and a length of up to 20 centimetres out of the rib-side. The sylvinite samples of the Starobin salt deposit were excavated from the third potassium horizon and underlying rock salt and chalky clay (Krasnoslobodsk mine).

For the Verkhnekamsk salt deposit, in addition to materials drilled out of the walls of the mine (Solikamsk field), samples of almost all the saline layers were excavated with the use of № 704-1 surface hole drill (Polovodovsk field). The production string was installed a few meters below the rock overlying the salt deposit. The mud flush was made exclusively from magnesium chloride, which decreased the possibility of core invasion with post-salt and pre-salt materials.

The core material was dissolved in water until the soluble salts were completely washed out. The resulting insoluble residue was separated into two classes (more than and less than 0.25 mm in size). Each class was separately studied on a VEGA 3 LMH scanning electron microscope.
microscope with an Oxford Instruments INCA Energy /X-max 250 20 x-ray energy-dispersive microanalysis system.

The dimensions of the coccoliths were recorded. The veracity of the findings can be confirmed by their presence alongside clastogenic clay particles, authigenic carbonates, sulphates, crystalline silica and feldspar in shallow halopellite interbeds (0.5-2 mm deep) – formed at the beginning of a yearly cycle of sedimentation. In a single case coccoliths were found right at the newly-made cleavage of a saliferous rock.

Results

Coccoliths from four species of coccolithophores were identified in the underlying salt, at the border between the sylvinite and carnallite zones in the Verhnekamsk deposit (Fig. 3). The elliptical placolith *Prediscosphaera ponticula* (Bukry, 1969; Perch-Nielsen, 1984) (*Prediscosphaera cretacea ponticula* (Bukry, 1969)) has two rows of non-overlapping panels (n=16) of equal size, with each panel being in the shape of a trapezoid. The distal plate has a narrow, internal loop consisting of small cubic elements. The cross-bars of the inner cross are multi-composite. They consist of four separate parts, and connect up to the corners of the central square (at the base of the core). The diameter of the placoliths along the long axis is 6.4-8.7 µm, which is larger than the diameter of the nominal subspecies *Prediscosphaera cretacea* (Bukry, 1969). The *Loxolithus armilla* coccolith’s (Black in Black & Barnes, 1959; Noël, 1965) elliptical bezel consists of a number of left-handed overlapping elements (n ~ 40).

The central area is wide and open, with a diameter of 6.2-6.0 µm. *Watznaueria barnesiae* (Black in Black & Barnes, 1959; Perch-Nielsen, 1968) is represented by coccoliths and coccospheres sized between 6.4-7.5 µm. Coccoliths from the distal side are represented by two multidirectional cycles. The central area in most cases is covered by a large number of small elements. The proximal shield consists of large elements with triangular end-points. Major loxoliths *Kamptnerius magnificus* (Deflandre, 1959) (13.9-14.0 µm) have a peripheral ridge, a central wide area with a longitudinal seam and a four-tier edge bezel.

Five species of coccolithophores have been identified in the Starobin deposit (Fig. 4) in the chalky clay and rock salt underlying the third potassium horizon, and in the second and third sylvinite layers of the third potassium horizon. In addition to *Watznaueria barnesiae*, *Kamptnerius magnificus*, and *Prediscosphaera ponticular*, two types of *Helicolithus trabeculatus* and *Gartnerago obliquum* were also discovered. The elliptical murolith *Helicolithus trabeculatus* (Górka, 1957; Verbeek, 1977) has a length of 6.7 µm and a bicyclic edge ring, as well as an asymmetrical diagonal cross consisting of wide composite beams. The large elliptical loxolith *Gartnerago obliquum* (Stradner, 1963; Noël, 1970) (length 10, 5 µm) has a complex edge bezel and central wide area with axial cross and polygonal elements, perpendicular to the axes of the cross.
Thus, the remains of single-celled algae, which are considered to be the biomarkers of the Mesozoic era, have been found in the Paleozoic sediments of the two salt deposits. All the above-mentioned species are typical for the second half of the Cretaceous, while the time range for *Watznaueria barnesiae* begins in the upper Jurassic.
Discussion and Conclusions

Coccolithophores are characteristic of waters with a salinity similar to that of sea-water. Despite the fact that the age of the identified species is considered to be more recent, there is no evidence to suggest that they were halophilous in the Paleozoic Era. The main obstacle for calcareous skeleton formation in vaporate basins is not the salinity, but rather the hostile acidic environment that existed in both troughs.

The most feasible idea is that normal marine waters brought the calcareous plankton into the halogen sedimentation basin. The coccolith discoveries occurring through the whole cross-section of the series we studied give us reason to suggest that the sea water intervention was permanent and not occasional. This is consistent with the idea that substantial (large and unique) potassium salt deposits such as the Starobin and Verkhnekamsk deposits could emerge only in conditions of constant sea water inflow. It is possible that coccolithophores could exist in the upper low-mineralized layer (galokline), only being immersed into the bottom brine layer after morphogenesis. There, through rapid (up to 7cm per year) salt deposition, and due to the recrystallization process (which can be clearly seen in similarly-aged – Paleozoic – carbonate rocks), they were preserved. There is a possibility that the eurypterid remains occurred in the Starobin salt deposits in the same way.

Thus, salt deposits have conditions which are optimal for preserving and maintaining calcareous nannoplankton skeletons. Furthermore, electron-microscopic studies of insoluble residue can considerably change the currently accepted limit of the coccolithophores' age lower bound. The localized nature of the potassium sedimentation within the sedimentary basins as well as the different hydro chemical trends of differentiation within the troughs, may serve to indicate their relative isolation. However, the finds of sea algae throughout the whole section of the saline series suggest that there was a constant connection to the oceans.

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Dalniy Tyulkas Section (Southern Urals, Russia): A Potential Candidate for the GSSP to Define the Base of the Artinskian Stage in the Global Chronostratigraphic Scale, New Data

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Abstract

The Dalniy Tyulkas section is represented by thick marine mixed carbonate-siliciclastic deposits of Lower Permian Age (Artinskian and Sakmarian Stages). The Dalniy Tyulkas section is proposed as GSSP for the lower boundary of the Artinskian Stage for International Geochronological Scale. A complex research of the Dalniy Tyulkas section (paleontological, lithological, geochemical, and paleomagnetic) was carried out for the first time. The lower boundary of the Artinskian stage is determined by the level of appearance of conodonts Sweetognathus whitei in the phylogenetic line Sweetognathus merrilli → Sw. binodosus → Sw. anceps → Sw. whitei → Sw. clarki. The diversity of fossil remains, the presence of numerous tuff interlayers, the accessibility of the section for further study and the possibility of a global correlation of the established boundary – all this allows us to propose the Dalniy Tyulkas Section as a stratotype of the lower boundary of the Artinskian Stage.

Keywords: Dalniy Tyulkas section, Permian, Sakmarian, Artinskian, conodonts, ammonoids, GSSP of the base of the Artinskian Stage

Introduction

The Dalniy Tyulkas is located on the right bank of the Usolka River at the northeastern margin of the city of Krasnousolsk, in the Republic of Bashkortostan, Russia (Fig. 1). The Sakmarian-Artinskian boundary interval in the Dalniy Tyulkas section is represented by beds of dark-colored carbonate mudstone, argillite, sandstone, and occasional bioclastic limestone with conodonts, fusulinids, radiolarians, rare ammonoids [1]. In the Artinskian part of the section, there are four interbeds of volcanic ash. Volcanic ash beds provide an extrapolated geochronological age of 290.1 Ma [2] for the base-Artinskian [3]. A complex research of the Dalniy Tyulkas section (paleontological, lithological, geochemical, and paleomagnetic) was carried out for the first time.
Material and Methods

Conodonts, ammonoids, spore and pollen were studied from the Sakmarian-Artinskian interval of the Dalniy Tyulkas section. Conodonts were extracted from the rock using a standard procedure for processing samples in 10% acetic acid. Ammonoids were found only in carbonate rocks of Artinskian Stage. The palynological characteristics of the Sakmarian and Artinskian deposits of the Dalniy Tyulkas section were obtained from the results of a spore-pollen analysis of 21 samples. The chemical composition of the rocks was determined at the Kazan Federal University using the S8 Tiger X-ray fluorescence spectrometer (Bruker, Germany).

Paleomagnetic studies were carried out in the rocks of the boundary (Sakmarian-Artinskian) interval 13.8 m thick (34 specimens). In Dalniy Tyulkas section 8 levels were probed for δ¹³C and δ¹⁸O values measurements.

Results and Discussion

The Sakmarian-Artinskian boundary deposits in the Dalniy Tyulkas section are characterized by assemblages of conodonts, ammonoids and plants. The section is described in [4].

**Conodonts.** Proposals to use the appearance of *Sweetognathus whitei* (Rhodes) for determining the lower boundary of Artinskian Stage were previously put forward by a number of authors [5]. We traced the gradual passage from *Sweetognathus anceps* Chernykh to *S. whitei* (Rhodes) for the first time, thus giving a complete picture of the development of these conodonts in the evolutionary lineage *S. postfusus* – *S. merrilli* – *S. binodosus* – *S. anceps* – *S. whitei* (Fig. 2).
The chronocline Sweetognathus binodosus – S. whitei can also be recognized in the lower Great Bear Cape Formation, southwest Ellesmere Island [6], and in the Florence limestones of the Chase Group Kansas. Apart from the North American sections, the lower boundary of the Artinskian Stage defined by the level of the first appearance of Sweetognathus whitei (Rhodes) in the chronomorphocline S. anceps – S. whitei is recognized in Bolivia [7], in China, in the Luosu section (Luodian, Guizhou) I the succession S. binodosus – S. whitei 316 m above the base of the section [8], and also in Korea [9] in the limestones of the Unomasa Formation in the “Stream bed” section, 18 m above the base, where the conodont assemblage is almost the same as one discovered by Rhodes (1963) in the Tensleep Sandstone in Wyoming [10].

Ammonoids. At 1.6 m above the Sakmarian-Artinskian Stage boundary, a small accumulation of Popanoceras annae Ruzhencev shells (sample 16RK14) was found. In the bioclastic limestones, many younger juvenile ammonoids are scattered 2.5 m above the Sakmarian-Artinskian boundary. The assembled collection of cephalopods (sample 16RK09) is dominated by Eothinites kargalensis Ruzhencev, which is often found in the Aktastyanian of the Southern Urals. Among the Eothinites, several specimens have prominent transverse ornamentation, previously identified as Eothinites aff. usvensis Bogoslovskaya. Possessing ornamentation very similar to representatives of E. usvensis from the Urminskaya Formation of the Middle Urals [11], the Tyulkas specimens differ in the less evolute shell. In addition to the Eothinites, the assemblage contains Popanoceras annae Ruzhencev, P. congregale Ruzhencev, and Daraelites elegans Tchernow (Fig. 3), which characterize the Artinskian Stage of the Urals. Paragastrioceratids are rare; they are represented by small specimens of Uraloceras involutum (Voinova) and U. gracilentum Ruzhencev (Fig. 3).

In addition to the Southern Urals, the species Uraloceras involutum (Voinova) is also known: in the Urminskaya Formation of the Middle Urals [11], in the Kosva Formation of the Pechora Basin [12], in the “Assistance” (Raanes) Formation of Ellesmere Island of the Canadian Arctic Archipelago [13], in the Jungle Creek Formation of the Northern Yukon Territory [14], in the Eagle Creek Formation of Alaska [15], as well as possibly in British Columbia and in Nevada [15]. Also here were found the shells of the genera Crinites and Aktubinskia, insufficiently well preserved.
In the natural outcrop of Dalniy Tyulkas Creek, the ammonoids are collected from Bed 8 (Sample 16RK07). The ammonoid assemblage of the Dalniy Tyulkas section is typical of the Lower Artinskian (Aktastynian) Substage. The entry Neopronorites skvorzovi (Tchernow), Uraloceras involutum (Voinova), U. gracilentum (Ruzhencev), Popanoceras tschernowi Maximova and P. annae Ruzhencev is an important indicator of the Sakmarian-Artinskian boundary. The interval of the Dalniy Tyulkas section containing Early Artinskian ammonoids is proposed to be designated as “Uraloceras involutum Beds”.

**Acritarchs, spores and pollen.** Acritarchs, spores and pollen. In all spore-pollen spectra of analyzed samples, pollen grains dominate (from 73 to 91%), whereas spores are only 9 to 27%.

This ratio of spores and pollen is typical of Permian deposits. Among the pollen, asaccate precolpate, striate pollen grains of the genus Vittatina – Vittatina striata Lub. predominate. In a somewhat smaller amount in the spore-pollen spectra, was two-mesh bilateral pollen represented by Gardenosporites pinnatus Krus., Vestigitisporites novus Tiw., Limitisporites sp., Platysaccus alatus (Lub.) Oshurk., Hamiapollenites bulaeformis (Samoil.) Jans. and other.

Significantly less common was the one-piece radial pollen and one-sided bilateral pollen Potonieisporites rimosus Schwar., Florinites luberae Samoil. More often there are spores of Crassispora sp. The taxonomic composition, of both spore and pollen, indicates the Early Permian Age of the host rocks [16]. Among the acritarchs, there are particularly many Leiospheridia sp., somewhat less Tasmanites sp. and even less frequent Inderites compactus (Lub.) Abr. et March. A similar ratio of acritarchs, spores and pollen with a significant dominance of the former was noted by I. Z. Faddeeva [16] for Sakmarian deposits of the Urals.

Thus, the analyzed spore-pollen spectra represent a single palynological assemblage, characteristic of the sediments of the Sakmarian and Artinskian Stages in the Dalniy Tyulkas section.

**Geochemical research.** Some oxides show changes near the Sakmarian and Artinskian Stages. Thus, there is a distinct increase in the content of zirconium, rubidium and yttrium towards the boundary. The Chemical Index of Weathering CIA [17], calculated \( \frac{Al_2O_3(Al_2O_3+CaO+Na_2O+K_2O)}{100} \), in clayey calcareous rocks in the Dalniy Tyulkas section size was 16-38, indicating weak weathering (or its absence). Cluster analysis showed a clear differentiation of “marine” and “terrigenous” groups of elements. The first group includes

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**Fig. 3.** Aktastynian ammonoid association from the lower part of Artinskian on the Dalniy Tyulkas section; (A) *Uraloceras gracilentum* Ruzhencev, DPMGI 16RK09-5, ventral view (A1, A5), lateral (right side) view (A2), apertural view (A3), lateral (left side) view (A4). (B) *Uraloceras involutum* (Voinova), DPMGI 16RK09-9, cross-section of the shell at D=10.6 mm (B1), ventral view (B2), lateral (right side) view (B3). (C) *Daraelites elegans* Tchernow, DPMGI 16RK09-1, lateral (left side) view (C1), ventral view (C2), lateral (right side) view (C3). The scale bars are 5 mm.
Ca, Mg, Sr, Ba, Mn, Cl, the second group is formed by Si, Fe, Ti, Al, Na, K and small elements – P, Cu, Zn, Rb, Zr. Based on the analysis of the chemical weathering indices of the CIA, it was shown that the climate on the border of the Sakmarian and Artinskian was predominantly arid, and the tectonic environment corresponded to the active and passive margins of the continents.

Carbonate carbon and oxygen isotopes. In Dalniy Tyulkas section, a sharp positive shift in values of δ¹³C is observed from -9.6‰ (layer 7-5) to -3.6‰ (layer 9-1) with amplitude 6‰. This shift correlates with a positive change from -11.7‰ to -2.2‰ (amplitude 9.5‰) in the bottom part of the Artinskian Stage in [18].

Magnetic properties of rocks. The studied Sakmarian-Artinskian deposits have low natural remanent magnetization, varying from (0.40-5.10) × 10⁻³ A/m, and the magnetic susceptibility does not exceed 18.9×10⁻⁵ SI units. The increase in magnetic characteristics occurs in the direction of limestone → carbonate concretions → calcareous argillites → argillites. It is established that two components are present in the composition of the natural remanent magnetization: the primary component, which is of orientational nature and the secondary, viscous component. The direction of the primary component is negative, and the studied formations correspond to the inverse polarity interval R1P of the Kiaman hyperzone. Intervals of positive magnetization were not detected.

Conclusions

In conclusion, we want to note the considerable spatial proximity of the lower boundary of the Artinskian, which is established by conodonts and ammonoids in the Dalniy Tyulkas section. The presence of an evolutionary trend Sweetognathus binodosus-S. aniceps-S. whitei with transitional forms between the members of the trend, allows us to assume the absence of breaks in sedimentation in the Sakmarian-Artinskian interval of the section. The diversity of fossil remains, the presence of numerous tuff interlayers, the accessibility of the section for further study, and the possibility of a global correlation of the established boundary-all this allows us to propose the Dalniy Tyulkas section as a stratotype for the justification of the lower boundary of the Artinskian Stage.

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The Mid-Tournaisian Carbon Isotope Excursion (TICE) in Limestones of the Middle Urals and Southern Trans-Urals

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Abstract

There is large C-isotopic positive excursion (TICE) in carbonate sections of the Tournaisian stage in the Middle Urals and Southern Trans-Urals. Based on the lithology of the studied limestones, we are able to assume that they were initially aragonite in composition. In this case the nature of the excursion may partly be associated with the fractionation of carbon isotopes between dissolved inorganic carbon (DIC) and carbonate sediments, and not only with glaciation, as previously supposed.

Keywords: Urals, Tournaisian, limestones, carbon isotopes, TICE, glaciation, aragonite

Introduction

There is evidence of Mid- (or Upper) Tournaisian glaciation in geological record of South America and Africa [1], [2], [3], [4]. It appears that this event correlates with the positive carbon isotope excursion in limestones, termed the “TICE” – mid-Tournaisian carbon isotope excursion [5]. Mid- and Upper Tournaisian limestones with high (absolute and relative to underlying deposits) values of δ13C are known from sections in North America, Western Europe, South China and Russia [6], [7], [8], [5], [9], [10]. Considered excursion coincides with the Siphonodella isosticha and Gnathodus typicus conodont zones and has a maximum magnitude (~7‰) in North America sections [6]. In the Timan-Pechora sections (Russia), δ13C values reach 8‰ [10]. In recent years, we discovered TICE in sections of the Middle Urals and Southern Trans-Urals.

Geological Position

We investigated two sections on the eastern and western slopes of the Middle Urals (Pershino and Druzhinino respectively) and the core of the Vostochno-Kurganskaya-53 borehole in the Southern Trans-Urals (basement of the West Siberian Plate) (Fig. 1). Carbonate deposits in the Middle Urals formed on the isolated carbonate platforms: Rezh platform (eastern slope), belonging to the paleo-oceanic sector of the Urals [11], [12], and Druzhinino platform (at the west), which occurred on the uplift within the eastern part of the East European platform [13], [14]. The Paleozoic sedimentation area in the Trans-Urals was attributed to the edge of the Kazakhstan paleocontinent, with influence of volcanic activity [15].
**Methodology**

The isotopic composition of carbon and oxygen was determined at Laboratory of Isotope Geochemistry and Geochronology (GIN RAS, Moscow), using Thermoelectron Corporation equipment, including the Delta V Advantage isotope ratio mass spectrometer and the Gas-Bench-II sample preparation device. We analysed bulk samples of limestones (the finest-grained material of rocks). The studied samples and standard KH-2, C-O-1, and NBS-19 were dissolved in orthophosphoric acid (H₃PO₄) at 50 °C. The δ¹³C values are expressed in parts per thousand – per mil (‰) – compared to the V-PDB standard. The reproducibility of δ¹³C measurements is within ±0.1‰.

**Results**

In the Pershino section limestones with high δ¹³C values correspond to the Kizelovian and to the lower parts of the Kosvinian Regional substages with a maximum at the Spinoendothyra costifera foraminifera zone. Particularly in this section of the Kizelovian Regional substage (which is the most complete section), gradual shift in the carbon isotopic composition occurs in its lower part and reaches maximum in the upper part (from 2.3‰ to 6.9‰; for details see [9]). In the lower part of the Kosvinian Regional substage (represented by sedimentary breccias) δ¹³C values equal to 3.6-4.9‰. In general, the interval with an anomalously high content of a heavy carbon isotope in the Pershino section has thickness more than 300 m (Fig. 2). It consists of peloidal and bioclastic-peloidal limestones with abundant oncolites formed by calcimicrobes.

Bioclasts are represented primarily by calcareous green alga. Deposits accumulated in conditions of carbonate compensation of downward island ark movements [16], [17].
We have studied a fragment (thickness is about 23 m) of the Druzhinino section, for which the Late Kizelovian-Early Kosvinian age is assumed [13], [18]. The δ13C values in limestones are 2.6-5.7‰ (Table 1). At the same time, the variation curve of the isotopic composition makes it possible to distinguish two separate peaks within the isotope excursion. The maximum levels are 5.2 and 5.7‰, separated by low δ13C, with minimum at 2.7‰ (see Fig. 2). The quarry is currently flooded, and underlying deposits could not be studied, so the real magnitude of the isotopic shift cannot be established. The main rock-forming components in these limestones are peloids and bioclasts of calcareous green algae, often intensively micritized. In the considered interval, the lithology of limestone remains fairly uniform, therefore, the detected δ13C variations are most likely due to changes in the isotopic composition of DIC.

Table 1. δ13C values in limestones of the Druzhinino section (the Middle Urals) and Vostochno-Kurganskaya-53 borehole (the Southern Trans-Urals). Red colour represents presumably diagenetically altered isotope values. For carbon isotopic composition of the Pershino section limestones see [9].

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<tr>
<td>VK-53 borehole</td>
<td>Upper Tournaisian</td>
<td>693.6</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>705.0</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>707.2</td>
<td>6.6</td>
</tr>
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<td></td>
<td></td>
<td>712.0</td>
<td>6.4</td>
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<td></td>
<td></td>
<td>718.0</td>
<td>6.4</td>
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<td></td>
<td></td>
<td>722.0</td>
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<tr>
<td></td>
<td></td>
<td>728.0</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>Lower Tournaisian</td>
<td>784.4</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>785.7</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>789.6</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>790.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

The Tournaisian limestones in the basement of the southern part of the West Siberian Plate occur at depths of 790.6–671.3 m (but cores from the depths of 784.4 to 728.6 m are absent). There is a fauna characterizing the layers of Upper Tournaisian Palaeospiroplectammina tchernyshinensis – Endothyra inflata zones (according to [18], [19]) at the base of the 728.6–671.3 m interval. The δ13C values in it vary from 5.2 to 6.6‰ (see Table 1, Fig. 2). The underlying core interval (790.6-784.4 m) is dated to the Early Tournaisian (with δ13C 1.9-3.5‰), wherein deposits with a lighter isotopic composition of carbon lie in its upper part. The Upper Tournaisian deposits here are diverse in lithology: oolitic sediments occur in the upper part of the interval, underlain by alternating bioclastic (consisting of skeletal fragments) and peloidal limestones. However, lithological changes are not reflected in the variations of the carbon isotopic composition of rocks.
Fig. 2. Stratigraphy, lithology and changes in carbon isotopic composition of limestones in Druzhinino section, Pershino section, Vostochno-Kurganskaya-53 borehole. Legend: 1 – bedded limestones; 2 – nodular limestones; 3 – carbonate sedimentary breccias; 4 – siliciclastic-rich limestones; 5–12: limestones with: 5 – peloids, 6 – calcareous green alga bioclasts, 7 – crinoids, 8 – shells and their fragments (primarily brachiopods), 9 – other bioclasts, 10 – oncoids, 11 – ooids, 12 – chert nodules. Open dots represent presumably diagenetically altered isotope values (δ^{18}O (V-PDB) of bulk samples < −10‰). Intervals of limestones with high values of δ^{13}C (intervals of positive excursion) are green-colored.

Discussion

The magnitude of the isotopic shift in the Upper Touraisian limestones of the Middle Urals and Southern Trans-Urals is about 3–4.5‰, so the Touraisian geological event is pronounced here (but it is significantly less than, for example, in North American sections). It appears that this event was related to glaciation [6], [8], [5], and associated with a sharp decrease in concentration of carbon dioxide in the atmosphere due to the intense burial of organic carbon in black shale formations.

However, not so high C-isotopic shifts may correspond to much larger glacioepisodes in the geological record (TICE is one of the largest excursions in the Phanerozoic). Moreover, a number of researchers (e.g., [20], [21], [22]) often do not take into account the Touraisian glacioepisode or do not include it in the Late Paleozoic Ice Age, probably due to the very local distribution of glaciers. Therefore, it can be ruled out that the shift in equilibrium between the main carbon reservoirs is not the only reason for the origin of TICE.

The limestones studied were most likely primarily aragonitic in composition. This assumption is based on the fact that the calcareous green algae fossils, which are very abundant in the considered rocks, as a rule, are initially aragonitic [23], [24], etc. In addition, modern peloidal carbonate deposits (e.g., sediments of the Great Bahama Bank) also mainly consist of aragonite [25], [26], and the Upper Touraisian limestones of the Middle Urals, as well as the peloidal lithofacies from the section of the VK-53 borehole (Fig. 3), have significant similarities with the Bahaman deposits in lithology.
It is widely known that aragonite precipitation is accompanied by a more intense fractionation of carbon isotopes between DIC and sediment than the formation of low magnesium calcite [27], [28], [8], [26]. It also appears [23] that approximately in the mid-late Mississippian there was a change of “calcite seas” to “aragonite seas” due to an increase in the Mg/Ca ratio of seawater. Despite the fact that S.M. Stanley & L.A. Hardie suggest that this transition is probably confined to the late Visean, our observations indicate that thick strata of carbonates composed mainly of aragonite were formed within the Uralian carbonate platforms in the late Tournaisian. Thus, the significant magnitude of the Middle-Late Tournaisian isotopic excursion can be associated both with glaciation and episode of aragonite sedimentation, by the superposition principle.

Fig. 3. Lithological features of the studied limestones: left – bioclastic-peloidal packstone with Nodosinella sp. in centre, Druzhinino section, sample D-1-1; middle – bioclastic-peloidal packstone with abundant Calcitarcha, Pershino section, sample 3027-30; right – bioclastic-peloidal packstone, Vostochno-Kurganskaya-53 borehole, sample 707.2. Note that the Middle Urals limestones contain numerous calcareous green algae bioclasts (which appears to be aragonitic), with evidence of intense micritization (indicate similarity with Bahamian peloidal limestones).

Conclusion

1. The Tournaisian geological event is clearly pronounced in sections of the Middle Urals and Trans-Urals, and the magnitude of the isotopic excursion is ~ 3-4.5 ‰.
2. Lithological features of limestones indicate that most likely they formed in the “aragonite seas”. Perhaps these deposits mark a transition from “calcite” to “aragonite” seas, or associated with the episode of intense aragonite sedimentation in the “calcite” sea.
3. One of the largest C-isotopic excursions in the Phanerozoic – TICE – may reflect the combined effect of glaciation due to the intense burial of $^{12}$C in black shale formations and a change in the seawater chemistry that favored the aragonite precipitation.

Acknowledgments

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Monitoring the Drying Process of an Oil-Saturated Whole Core Sample

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Abstract

This paper presents the results of an experiment monitoring the drying process of an oil-saturated whole core sample. The object of the study is oil-saturated limestone of Bashkirian age, taken from the Akan petroleum deposit.

Nuclear magnetic resonance (NMR) spectroscopy was used as a primary research method. In the depth range studied, two zones were distinguished based on the rate and specific aspects of the drying process. The drying process of a water-saturated sample was also compared. X-ray computed tomography (CT) was used to study pore structure, the heterogeneity of which may explain differences in drying patterns.

The study showed that drying process can be monitored using NMR, which can elucidate the effects of saturation type and pore structure on drying processes.

Keywords: nuclear magnetic resonance, drying process, whole core, X-Ray CT, carbonate core

Introduction

Rocks start to dry out immediately that drilling begins, and this is a continuous process. The fluid loss causes deformation of the rock, as well as the movement and redistribution of the remaining fluid inside the reservoir [1]. Thus, the reservoir properties (filtration-volumetric characteristics) can significantly change in the process [2].

Laboratory studies of core drying processes are widely used to determine different characteristics of rocks. In 1951, the evaporation method was first used to determine the amount of interstitial water in a porous medium [3]. Much work was also devoted to determining the minimum interstitial water content in core samples [4]. These works substantiate the use of the evaporation method as applied to various production tasks. The experiments described above were carried out on small arbitrarily-shaped samples.

In later studies, most of the experiments related to drying processes in rocks were carried out on standard core samples (plugs, 30 mm in diameter) [5]. However, samples suffer from mechanical defects while being cut. This procedure can have a major impact on various characteristics (wettability, for example) of the samples [6]. As a result, physical and filtration-volumetric characteristics of the core samples (especially those associated with the pore structure) can differ considerably from those of the original rock.

The reservoir properties obtained for the 30 mm core samples will most accurately reflect those of the whole core sample (and, therefore, the original rock) only if these samples are well-sorted coarse- or medium-grained sandstones, also called “traditional” reservoirs. However, there has been a systematic depletion of reserves in terrigenous reservoirs in recent years. This
is the major factor driving the current interest in carbonate reservoirs, with the hydrocarbon saturation ranging from 40 to 60%.

As a rule, carbonate deposits have a more complex pore structure than terrigenous rocks. Reservoirs of this type may have various pore structures; therefore, their petrophysical characteristics also range widely [7]. There were many attempts made to understand the influence of core sample size on the measurement results. For example, samples of various sizes were used to determine porosity and permeability, and the results were then compared with the well log data [8]. Petrophysical properties obtained from the whole core (instead of plugs) correlate better with the log data and better characterize the original rock [9].

There are a relatively small number of methods that can be used to estimate the amount of fluid contained in the whole core sample. One of these methods is NMR spectroscopy, which is quite reliable and non-destructive [10]. NMR is widely used both in the field (as one of the logging methods) and in laboratory studies [11], [12], [13]. Laboratory NMR spectroscopy can be used to evaluate the porosity (total and effective) and the free fluid volume (for pore size estimation) [14].

Previously, NMR spectroscopy was already used for the study of drying [15] and water saturation [16], [17] processes in the whole core. Characteristic patterns were identified in the drying process of the water-saturated core sample.

This work is devoted to the monitoring of the drying processes in the oil-saturated whole core sample.

Methodology and Object of Research

A test survey was carried out on the whole core sample (67 mm in diameter) using NMR spectroscopy. The exposed deposits are of Bashkirian age (Carboniferous System).

The studies were performed using the "NMR-Core" installation [18] developed jointly by the specialists of TNG-Group LLC and Kazan Federal University. The device allows the study of a whole core with a diameter of up to 110 mm and a length of up to 1000 mm (the measurements can be taken in increments of 10 mm along the core axis).

The measurement result is the transverse relaxation curves. The curves are then converted into spectra, and porosity is calculated [19]. A reference sample with known parameters is then used to normalize the porosity coefficient obtained during the measurements.

Before measuring the total pore volume, the measurement settings were adjusted using the first part of the core extracted from the well. Measurements were carried out using the Carr-Purcell-Meiboom-Gill pulse sequence [20]. As a result, the following measurement settings were selected: pulse width – 2000 msec; pulse spacing – 0.3 msec; repetition time between pulse groups is 3000 msec; the quantity of pulses – 4.

Lithologically, the whole core sample consists of pseudo-brecciated limestone (rudstone), irregularly oil-saturated, dark-brown with numerous light-gray veins of dense original rock. The original rock is carved with subvertical fractures filled with oil. There are also layers of limestone with packstone structure (Fig. 1).

The measurements were taken every 24 hours from the moment of extraction. Each measurement showed a decrease in the hydrogen content, indicating fluid loss from the pore volume. After 360 hours, the time between measurements was increased because of the slow drying rate. The last measurement was performed 552 hours (23 days) after the extraction.

Figure 1 shows the results of NMR spectroscopy performed on the oil-saturated whole core sample.
Results and Discussion

The curve of the whole core porosity was chosen for the analysis. The decrease in porosity determined by NMR spectroscopy indicates the active process of fluid evaporation, since the amplitude of the transverse relaxation curve is associated with the fluid content in the core sample [21].

The measurement result is a set of porosity curves. Figure 1 shows the curves obtained for the studied interval. The first 4 cm in the diagram correspond to the reference sample. The measurements were normalized to make the porosity reduction clear. In absolute values, the porosity was 16%. For better visual perception, not all measurements are shown in the figure.

The porosity reduction showed by NMR spectroscopy is due to the decrease in fluid saturation. This, in turn, reflects the drying process.

It can be noted that the main fluid loss occurs in the first 24-48 hours after the extraction. Two types of drying were identified during the analysis of the curves.

Figure 2 shows the curves that refer to the first type of drying. For clarity and convenience, the diagram shows the porosity reduction curves for several neighbouring points. The sharpest decline in fluid saturation occurs in the first 48 hours. During this short period of time, the core sample loses up to 30% of its fluid. During the next 100 hours, the drying rate starts to drop, averaging 20%. After 144 hours, the drying rate is reduced to a minimum and is less than 2% per 100 hours.

Figure 3 shows the curves related to the second type of drying. There is an area of intensive evaporation as well, which lasts 72 hours. The drying rate at this stage is 45% per 72 hours (almost the same as for the first type). The drying process then continues at a rate of about 7% per 100 hours. After 336 hours, it almost completely stops.
During the drying process, the fluid first evaporates from the surface pores, which are in direct contact with the environment. This is why the first stages (highlighted in Figures 2 and 3) of the both drying processes are so similar. In Figure 2, rather intense evaporation can be seen within 120-144 hours. After that, the drying rate drops significantly, but does not stop completely. In Figure 3, the drying rate gradually decreases after the first intensive stage to an almost complete stop at 336 hours.

The core sample from between 0.36-0.58 m was studied using X-Ray CT in order to analyse the pore structure in more detail. X-Ray CT has a limited resolution when working with a whole core. It can detect micropores of 140 microns in size.
According to the X-Ray CT data, the parts of the core sample characterized by the first type of drying are the areas with larger pores, which are clearly visible during the scanning. It is obvious that the evaporation is more intense in these areas, and the oil stains can be clearly seen on the sample’s surface. The second type of drying is typical for the denser areas with no large pores or caverns. Once evaporated from the near-surface part, the fluid from the central part starts to move very slowly through the system of pore channels towards the surface.

Previous work on monitoring of the drying processes in the water-saturated whole core sample revealed two types of fluid evaporation [15]. Water behaves differently from oil while evaporating. 90% of the initial water content could stay in the porous space after 200 hours.

Oil-saturated samples lose 50% of their fluid (regardless of the pore structure) over the same 200 hours. During the first 200 hours, oil evaporates faster than water. However, after 456 hours, the water left the porous space of the sample completely. The oil-saturated sample dried out almost completely after 550 hours, but some oil still remained in it. The reason for this is most likely the blockage of pore channels by oxidized oil. For a deeper understanding of this effect, additional NMR and X-Ray CT studies on smaller samples are needed.

**Conclusion**

The experiments showed the possibility of using NMR spectroscopy to study the drying process of oil-saturated whole core samples. The study showed that most of the fluid in the oil-saturated core sample evaporates during the first 48 hours, while in the water-saturated sample half of the water remains for 200 hours. This is primarily due to the higher volatility of light hydrocarbons compared to water.

Data analysis revealed 2 types of drying, which are different from what could be seen previously for the water-saturated core. During the first 200 hours, hydrocarbons evaporate much faster than water. Subsequently, the rate of oil evaporation is sharply decreased due to partial or complete blockage of pore channels. Undoubtedly, the pore structure affects the drying rate, as was also shown in this study. This research will continue on samples of various sizes and saturation in order to get a better understanding of the factors that may have an additional impact on the drying process.

**Acknowledgements**

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Paleomagnetism and Magnetostratigraphy of Permian-Triassic Redbeds of the Balebikha Section (Russia, Severnaya Dvina River)

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Abstract

Thanks to the fundamental research of the founders of the Russian paleomagnetic school – Alexey Khramov, Arkadiy Molostovsky and Boris Burov – the magnetostratigraphy of many Permian-Triassic (P-Tr) sections of the Russian Platform is developed at relatively high level. However, the paleomagnetic re-study of key P-Tr sections of the Moscow Basin (Synclise) performed in recent years clearly demonstrates the need to expand the scale of high-resolution paleomagnetic studies performed at the modern methodological and analytical level with the aim to clarify the existing magnetostratigraphic scales and obtain new reliable paleomagnetic data. In this paper, we present the results of a paleomagnetic study of the Permian-Triassic section of the Balebikha in the Vologda region, in which three magnetic polarity zones were revealed. Moreover, the existence of an anomalous magnetization interval similar to that found in the uppermost Permian sediments of the Nedubrovo section was confirmed.

Keywords: paleomagnetism, Permian, Triassic, East European platform

Introduction

Magnetostratigraphy of the Permian-Triassic boundary of the East European platform is discussed in many of Russian and foreign publications. Nevertheless, the question of development of a reliable regional magnetostratigraphic scale for the Paleozoic-Mesozoic boundary of the Russian Basin remains largely unsolved due to significant changes of the paleomagnetic method in the beginning of XXI century and the improvement of its analytical capabilities. So, the existing magnetostratigraphic scales of the key Permian-Triassic sections have to be checked. At the same time, there are a lot of P-Tr sections which still do not characterized by paleomagnetic studies. In this work, we present new paleomagnetic data on the P-Tr section of the Balebikha, located in the north of the Russian sedimentary basin.

The Balebikha section is located on the right bank of the Severnaya Dvina river opposite of Veliky Ustyug city (60.72°N, 46.39°E). It represents by the red-coloured terrigenous rocks with thin layers of limestone and marl of the uppermost Permian and the lowermost Triassic.

Field studies were carried out in 2016 and 2018. Paleomagnetic sampling was quite difficult because of high water content in the rocks – upper Permian clays act as a hydroseal here; however, we were able to take oriented samples from the interval close to the P-Tr boundary, namely from layers 5, 8 and 9, according to [1] (Fig. 1). The total thickness of the sampled interval is 5 m.

Layer 5 is represented by pied light gray and red carbonate clays. Layer 8 consists of pied, mainly red-coloured clays and siltstones. In the upper part of the section there is a contact
between the clays of the Salaryovo Formation of the Vyatkian and millstones and conglomerates with pebbles of carbonate rocks and sandstones of the Vokhma Formation of the Indian (layer 9).

**Methods**

In total, 90 oriented samples were taken, however, due to the fragility and high-water content of the rocks, only 60 samples were subjected to laboratory treatment. We used the magnetic compass to orient the samples; the local declination was accounted for according to the IGRF model (12th generation). Anisotropy of magnetic susceptibility (AMS) and bulk magnetic susceptibility were measured for all samples using KLY-4S kappabridge (AGICO, Czech Republic). All samples were subjected to detailed temperature demagnetization, some sister-samples were also treated by an alternating magnetic field with the amplitude up to 130 mT. Magnetic treatment was carried out in the laboratory of the Main geomagnetic field and geomagnetism of the IPE RAS (Moscow) using the cryogenic SQUID-magnetometer (2G Enterprises, USA). The samples were demagnetized in a non-magnetic furnace MMTD80 (Magnetic Measurement, UK). The results of magnetic treatment were processed using the software package of R. Enkin [2], which uses the PCA method to isolate the magnetization components [3].

**Results**
The mean magnetic values for each layer (value of the natural remanent magnetization (NRM), bulk magnetic susceptibility and the Koenigsberger ratio (Q)) are given in Table 1. We should note that previous results of rock magnetic studies [4, 5] indicate that the Permian-Triassic boundary within the Moscow Basin is characterized by a sharp change in the scalar magnetic parameters, such as the value of the NRM and magnetic susceptibility. Our data show that the Balebikha section is not an exclusion and its rock magnetic values are increasing around the Permian-Triassic boundary (Table 1). The Koenigsberger ratio (Q) vary from 0.1 to 0.8, which is typical for rocks with the detrital nature of magnetization (DRM).

**Table 1. Mean rock magnetic parameters of the Balebikha section**

<table>
<thead>
<tr>
<th>Age</th>
<th>NRM, A/m</th>
<th>Bulk magnetic susceptibility $\chi$ ($10^{-6}$) SI</th>
<th>Koenigsberger ratio $Q_{\text{mean}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 9</td>
<td>T$_1$</td>
<td>12.88E-03</td>
<td>35.42</td>
</tr>
<tr>
<td>Layer 8</td>
<td>P$_3$</td>
<td>4.87E-03</td>
<td>24.04E+01</td>
</tr>
<tr>
<td>Layer 5</td>
<td>P$_3$</td>
<td>2.23E-03</td>
<td>8.22E+01</td>
</tr>
</tbody>
</table>

The AMS ellipsoids are characterized by isometric to flattened shapes: the minimum axes (k3) are mostly subvertical, and the maximum (k1) and intermediate (k2) are evenly distributed in the equatorial plane; this pattern of AMS is typical for sedimentation in the lakes and calm rivers. The degree of anisotropy ranges from 4.0 to 9.5%.

The paleomagnetic record in the studied samples is quite noisy. As a rule, the NRM is represented by two components of magnetization: low-temperature (viscous, having a modern age) and high-temperature – characteristic (ChRM) of normal and reverse polarity (Fig. 1). The paleomagnetic record of good quality is found in 37 samples: 7 samples carry the most stable magnetization component of normal polarity (N), 26 samples – reversed polarity (R).

In four samples belonging to the same stratigraphic level (top of layer 8, Fig. 1) and representing approximately 30 cm of thickness, the direction of the most stable magnetization component is enigmatic for the Permian-Triassic of the East European platform. Its mean is characterized by shallow inclination and WSW declination. It should be noted that similar interval with anomalous directions of high-stable component of NRM was recently detected in the Nedubrovo section [6]. The presence of the same anomalous interval in the Balebikha section can be considered as an indication on its regional distribution and gives the opportunity to use this paleomagnetic zone as a regional (probably, global?) magnetostratigraphic marker.

Magnetoostratigraphic interpretation of the paleomagnetic data provides the basis to carry the lower part of the layer 5 and the layer 9 to the two zones of normal polarity, while the layer 5 and a large part of the layer 8 belong to the zone of reversed polarity (Fig. 1). It is important to note that the lower part of the layer 8 corresponds to the zone of reversed polarity, i.e., there is no zone of normal polarity which includes P-Tr boundary – the result that has recently been observed in some P-Tr sections [7]. Taking into account the erosion contacts of layer 8 and the overlying Triassic sediments, it can be assumed that this normal polarity zone was eroded at the beginning of the Triassic.

The mean paleomagnetic direction of the ChRM (the reversed polarity directions are reversed) is N=33, D=27.5°, I=45.7°, k=23.9, a$_{95}$=5.2° in the stratigraphic coordinates. The obtained ChRM direction is expected for the Permian and Triassic for the East European platform; the corresponding paleomagnetic pole has the following coordinates: Plat=51.6°, Plong=185.0°, dp/dm=4.2°/6.6°, the paleolatitude of the Balebikha section at the time of its formation is defined as 27.1N.
Conclusions

The main results of the first detailed paleomagnetic studies of Permian-Triassic rocks from the Balebikha section are:

1. Three magnetic polarity zones are distinguished: the upper part of the section, which corresponds to the terminal Permian, the zone of normal polarity is replaced by the zone of reversed polarity. The lower Triassic sediments carry the ChRM of normal polarity.
2. An increase of the mean rock magnetic values (NRM, magnetic susceptibility) is observed in the nearest proximity to the P-Tr boundary.
3. The presence of the anomalous magnetization zone, which direction is similar to that in the Nedubrovo section [6], allows its use as a regional, and, possibly, global magnetostratigraphic marker.

The obtained results indicate the availability of the Balebikha Permian-Triassic section for detailed paleomagnetic studies with the aim to develop the regional magnetostratigraphic scale of the Russian Basin. The calculated paleomagnetic pole can be considered as sufficiently reliable P-Tr pole for the East European platform and can be used for paleotectonic and other reconstructions.

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REFERENCES

Foraminiferal Biostratigraphy of the Serpukhovian Stage (Mississippian) in the Zaborie Section (Moscow Basin)

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Abstract

Biostratigraphy, taxonomy, morphology and evolution of foraminifers *Loeblichia paraammonoides*, *L. ukrainica*, *L. minima* and *Cepekia cepeki*, potential markers for the base of the Serpukhovian and the boundaries of the Serpukhovian regional substages of the East European Platform, are discussed.

*Keywords: Foraminifera, Zaborie, Moscow Basin, morphology, taxonomy, biostratigraphy*

Introduction

The Zaborie Quarry in the Moscow Basin (Fig. 1) is the type section of the Serpukhovian Stage and represents one of the best studied Serpukhovian marine carbonate successions of the East European Platform (EEP).

![Fig. 1. Sketch map of the Moscow Region showing the Zaborie Quarry and other type Serpukhovian sections](image-url)
Although the quarry is now largely landfilled, the succession has been extensively sampled for foraminifers and provides an invaluable source of information on the distribution of many stratigraphically important foraminiferal species. The initial data [3], [4] provided general information that was later detailed. The succession was subdivided into zones [5] according to the first foraminiferal scale [6] and into regional substages of the EEP [5]. Lithology, facies and sedimentary environments were published [7], [8], the Viséan-Serpukhovian boundary and regional substages were defined [9] according to [1] and by correlation with Western European sections [10]. Due to a high taxonomic diversity of foraminifers and the presence of foraminiferal zonal markers, the regional substages of the Serpukhovian (Tarusian, Steshevian and Protvian) have been defined by foraminiferal associations. The species Neoarchaediscus postrugosus (Reitlinger) and Janischewskina delicata (Malakhova) are considered as potential basal Serpukhovian markers [11], because they are found in the EEP, Western Europe, and England [12]. Note that the problem of the definition of the base of the Serpukhovian and GSSP remains open, because the level of the first appearance of the conodont marker (Lochria ziegleri) in sections often does not coincide with the levels of the appearance of foraminiferal markers. In addition, the taxonomy of the potential markers needs to be clarified [11].

Therefore, a new discussion on the foraminifers from Zaborie, where most foraminifera are of Serpukhovian age, can be very useful for interregional correlations [13].

Results and Discussion

The carbonate succession of Zaborie contains four foraminiferal zones and regional substages of the EEP [1], [2].

Upper Viséan

Endothyranopsis sphaerica-Eostaffella tenebrosa Zone, Venuvian Regional Substage (Fig. 2). The beds containing this assemblage are at the base of the quarry, and were usually flooded even before the quarry was landfilled, with only their uppermost part being exposed.

These are represented by packstone-wackestone. The foraminiferal association, in addition to the zonal index species, includes Eostaffella ikensis Vissarionova, Loeblichia paraammonoides (Brazhnikova), Pseudoammodiscus sp. and Neoarchaediscus parvus Rauser-Chernousova, commonly Endostaffella spp. and Neoarchaediscus ex gr. parvus Rauser-Chernousova (Plate 1). This assemblage is undoubtedly Upper Viséan. The presence of Eostaffella aff. tenebrosa and E. ikensis, which are characteristic of the Venuvian in the Moscow Syncline [2], [13], as well as Loeblichia paraammonoides (Brazhnikova), which appears from the upper Brigantian in Wariantian Belgium, suggests the correlation of the Venuvian E. tenebrosa-E. sphaerica Zone with the Upper Brigantian MFZ15 foraminiferal zone [10]. These data contradict the statement [14] about the Tarusian age of this interval in the context of Zaborie.

Neoarchaediscus postrugosus-Janischewskina delicata Zone, Tarusian (Beds 3 to 14, Fig. 2). Packstone-bioclastic wackestone. The position of the boundary reflects a significant increase in foraminiferal diversity. Starting from Bed 3 (Fig. 2), where “Millerella” tortula Zeller, Neoarchaediscus postrugosus (Reitlinger) FAD, and a little higher (Bed 4) Janischewskina delicata (Malakhova) and Loeblichia ukrainica (Brazhnikova), Paraarchaediscus stilus (Grozdilova and Lebedeva), Pseudoendothyra globosa Rosovskaya, Rectocornuspira sp. FADs (Fig. 2) occur; these foraminifers are undoubtedly Tarusian, Serpukhovian [1] (Fig. 2) Higher up, throughout the Tarusian (Beds 5-14), no noticeable changes are observed in the foraminiferal assemblage [5, p. 45].

Eostaffellina decurta Zone, Steshevian (Beds 14 to 47). Poly-bioclastic wackestone.
According to the updated data (Beds 15-47, Fig. 2), the lower boundary is drawn at the FAD of *Eostaffellina decurta* [6]. The diversity of the foraminiferal association from this level is significantly increased. Together with the FAD of *Loeblichia minima* Brazhnikova, *Loeblichia paraammonoides* (Brazhnikova) is recorded (Fig. 2) in the association with *Cepekia cepeki* Vašíček and Růžička. Among the listed forms, the FAD (First Appearance Datum) of *Cepekia cepeki* and *Cepekia spp.* at the base of Bed 15 simultaneously with *Eostaffellina decurta* (Fig. 2) may be used as an additional marker of the Tarusian-Steshevian boundary. Previously [7, p. 41], the Tarusian-Steshevian boundary was placed between Beds 8 and 9 by the level of the highest concentration of stone-like voids of the third root horizon, and did not have a paleontological characterization. Beds above Bed 15 show the most interesting changes in the foraminiferal composition (Fig. 2) as the FAD of *Eostaffellina paraprotvae* (Rauser) (Bed 28) is within the Steshevian [2].

**Fig. 2.** The stratigraphic log of the Zaborie Section (Moscow Synclise, EEP) showing the distribution of foraminifera. FOD – first occurrence datum. The log is after [9].
Explanation of Plate 1

Plate 1. Some foraminiferal markers from the Uppermost Viséan-Serpukhovian of Zaborie: Uppermost Viséan, Venevian: 4, 5, 22–30, Bed 2. Fig. 4. *Pseudoammodiscus* sp., median section, Bed 4, 1786. Fig. 5. *Loeblichia paraammonoides* (Brazhnikova), median section, Bed 2, 1781. Fig. 22. *Endostaffella fucoides* Rosovskaya, axial section, Beds 2–15, 1776. Fig. 23. *Endothyra obsoleta* Rauser-Chernousova, axial section, Bed 2, 1779. Fig. 24. *Eostaffella proikensis* Rauser-Chernousova, axial section, Bed 2, 1787. Fig. 25. *Eostaffella tenebrosa* Vissarionova, axial section, Bed 2, 1783. Fig. 26. *Eostaffella ikensis* Vissarionova, axial section, slightly oblique, Bed 2, 1783. Fig. 27. *Endostaffella parva* Möller, axial section, Bed 2, 1775. Fig. 28. *Paraarchaediscus minae* Grozdilova, axial section, Bed 2, 1787. Fig. 29. *Eostaffella pseudostruvei* Rauser-Chernousova, axial section, Bed 2, 1778. Serpukhovian Stage: 1-3, 6-21. Figs. 1-3. *Rectocornuspira buskensis* (Brazhnikova), Figs. 1-2 axial sections, Bed 4, 1775. Fig. 3. median section no complete, Bed 4, all are Tarusian, 1866, 2140, 1912 consistently. Fig. 6. *Loeblichia paraammonoides* (Brazhnikova), axial section, Bed 15, Steshevian, 1886. Fig. 7. *Loeblichia ukrainica* (Brazhnikova), axial section, Bed 3, Tarusian, 1809. Figs. 8, 16. *Loeblichia minima* Brazhnikova, 8–axial section, Bed 15, Steshevian, 2203, 16–median section, Bed 15, Steshevian, 2203. Fig. 9. *Neoarchaediscus postrugosus* Reitinger, axial section, Bed 3, Tarusian, 1810. Figs. 10, 11. *Millerella “tortula”* (Zeller); 10–axial section, 11–median section, Bed 3, Tarusian, 1826, 1814 consistently. Fig. 17. *Eostaffellina decurta* (Rauser-Chernousova), axial section, Bed 15, Steshevian, 2152. Figs. 12-15, 18-21. *Cepkeia Růžička and Vašíček; all axial sections, except for 20, 21, which are incomplete median sections; all are from Bed 15, Steshevian, Figs. 18-20. *Cepkeia cepeki* Růžička and Vašíček. 2141, 2174, 2195, respectively. *Cepkeia* spp. all axial sections, 2162, 2189, 2185, 2201 respectively. Note. White arrows in Figs. 12, 14, 18, 19–mark shell wall layers. Collections are housed at PIN RAN, laboratory protistology, specimen nos. as indicated; scale bar equals 0.1 mm.
Biostratigraphy, Morphology and Evolution

A distinctive feature of the Zaborie section is the manifestation of low-water and relatively deep-water shelf depositional settings associated with the Viséan-Serpukhovian boundary [9]. A new transgression at the beginning of the Serpukhovian was reflected in the development of foraminifera by the appearance of planispiral shells tolerant of deep-sea environments. They were known and illustrated earlier [5], but their biostratigraphic potential was not recognized. A closer examination of the assemblages in the section showed that *Loeblichia paraammonoides* (Brazhnikova) enters from the end of the Venevian (Fig. 2). After it, *L. ukrainica* (Brazhnikova) enters from Bed 3 at the base of the Tarusian (Fig. 2), and *Loeblichia minima* enters somewhat above (Bed 15). These three species constitute a continuous evolutionary lineage. Recently, the foraminiferal species listed above have been identified in Spain, Ireland and Scotland [12]. The succession of these species in the Viséan and Serpukhovian sections of the EEP (Fig. 2) can be used for correlations of sections in the EEP, Western Europe and England. Two of the taxa, *L. paraammonoides* (Brazhnikova) and *L. ukrainica* need to be researched in greater detail because of the ambiguity of their taxonomy. When first established, *L. paraammonoides* was assigned to *Nanicella* [15, p. 36], while *L. ukrainica* was assigned to *Quasiendothyra* [16, p. 38]. Rosovskaya [18, p. 62] assigned *L. ukrainica* (Brazhnikova) to *Loeblichia* Cummings 1955 [17]. Bearing in mind the above explanations, it is legitimate to consider the evolution of the species as *L. paraammonoides* – *L. ukrainica* – *L. minima*. These appear successively in the Zaborie section (Fig. 2) and at the same time have a great similarity in morphology, which is probably due to their genetic relatedness. They differ from one another in morphology of the initial part of the shell and the number of plane-helical volutions (Plate 1, Fig. 1, 7, 16).

The evolution of the group of species *Loeblichia paraammonoides* – *L. ukrainica* – *L. minima* followed the path to the formation of endothyroid shell coiling in the juvenarium (Plate 1, Fig. 1, 7, 16). *L. paraammonoides* probably comes from *Quasiendothyra kobeitusana* Rosovskaya [18, pl. 2]. Having a plane-spiral shell and a significant number of volutions, *L. paraammonoides* appears at the end of the Venevian to form endothyroid coiling of the initial volution from the initial chamber. Thus, at Venevian-Tarusian boundary, *L. ukrainica* appears. It is distinguished from the ancestral form by endothyroid coiling of the juvenarium, and a reduced number of plane-spiral volutions. *L. ukrainica* at the end of the Tarusian shows signs of recapitulation of characters as it apparently restored the symmetry of shell coiling in the juvenarium. This process is accompanied by a decrease in the number of volutions. Finally, *L. minima* appeared at the Tarusian-Steshevian boundary. It is distinguished from the ancestral form of *L. ukrainica* by the absence of the endothyroid juvenarium and a smaller number of plane-spiral revolutions. In this case, the sign of plane-spiral coiling in all species of this group is preserved in most of the shell (Plate 1, Fig. 6-8). The opinion of some authors [21] on the suspension of the evolutionary development of foraminifera is not consistent with the results of a study [23] on the emergence of many new taxa after a depositional gap among many groups of fossil organisms and foraminifera [19]. The simultaneous appearance of ancient and young taxa at the Serpukhovian boundaries or near them (Fig. 2) suggests that the events associated with the depositional gap at Venevian-Tarusian boundary did not affect the evolution of foraminifera [19].

The bio-stratigraphically important genus *Cepekia* Vašíček and Růžička, 1957 also need clarification. *Cepekia cepeki* occurs in the section from the base of the Steshevian (Fig. 2). This event is observed simultaneously with the FOD of the zonal species *Eostaffellina decurta*. *Cepekia* was originally described from the Czech Republic [22].
Fig. 3. Distinctive features of Cepekia cepeki Růžička and Vašíček (Plate 1, Fig. 19): 1-3. The numbers mark the shell wall layers: 1 – internal layer, 2 – medium layer, 3 – external layer.

The geographical range of this genus is limited. In our material there are several Cepekia cepeki shells from the Steshevian in the Novogurovsky quarry [19, Fig. 4, p. 27, pl. 5, Fig. 26-29] as addition to Zaborie. Brazhnikova et al., [16] used the name Cepekia (nom. nud.) as a subgenus of the genus Rectocornuspira. Cepekia was identified in Western Europe [12]. Later [ibid.] it has been suggested that the genus Cepekia probably had a wider range, but was probably overlooked in many regions because of the slight difference between the genera Cepekia and Rectocornuspira. We can agree with the authors on this point. Indeed, the initial description of Cepekia [22, pls. XI, XII, figs. 2a, 2b] and especially the photograph of the holotype shows a shell isolated from the rock matrix, while the drawings of the original material (pl. XVII, Fig. 9) do not give a clear idea of the morphology of the shell. However, both genera with significant morphological similarities [20] differ from each other in wall structure. Rectocornuspira is characterized by a single-layer wall of microgranular structure (Pl. 1, Fig. 1-3), while in Cepekia the three-layer wall is clearly visible in all shells, as can be seen in (Plate 1, Fig. 12, 14, 18, 19).

Conclusions

A closer examination of the foraminiferal assemblages in the Zaborie section showed:

1. The species Loeblichia paraammonoides (Brazhnikova) appears in the Zaborie quarry at the end of the Venevian, so and its first entry are characteristic of the Upper Venevian.
2. The species L. ukrainica (Brazhnikova) first appears at the base of the Tarusian and marks the base of the Serpukhovian.
3. The species L. minima (Brazhnikova) enters near the Tarusian-Steshevian boundary, and marks it. This is different from what was previously known about the distribution of this foraminifer species.
4. The species L. paraammonoides – L. ukrainica – L. minima are members of a single phylogenetic lineage and are found in a geochronological succession. Hence, in Zaborie, the base of the Tarusian (and Serpukhovian) is defined by the first appearance of a known species in a phylogenetic lineage of the genus Loeblichia Cummings, 1955.
5. The species Cepekia cepeki occurs in the section from the base of the Steshevian. This event is observed simultaneously with the appearance of the marker species Eostaffellina decurta. Cepekia cepeki can be considered an additional marker of the Tarusian-Steshevian boundary.

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Palynological Evidence of Southwestern Gondwana’s Prolonged Carboniferous-Permian Glaciation: Towards a Refined Biotic Deglaciation Model

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Abstract

The Late Palaeozoic Ice Age (LPIA) represents one of the most extreme climate transformations in Earth history, transitioning from icehouse to greenhouse conditions. However, the controversial discussion on the termination of glaciation demonstrates the need for a more robust stratigraphic control including climatic palynoevents calibrated by radiometric data. New palynological data from Karoo basins of southwestern Gondwana (South Africa, Mozambique) reveal thick lacustrine deposits of Artinskian age, documenting the final glacial retreat with melt waters supplying broad lowland sinks. The switch from cold to cool-temperate conditions is displayed in the pollen record with the first taeniate bisaccate elements occurring in the Artinskian, clearly marking a change in the upland flora. This prominent floral signature indicates that at least in the southwestern part of Gondwana glaciers still characterized the upland regions during the late Cisuralian. Palynological evidence of a prolonged glaciation also includes marine phytoplankton associations and their response on meltwater influx into marine basins during the late Cisuralian.

Keywords: Permian, palynology, lake deposits, deglaciation, southwest Gondwana

Background

The Late Palaeozoic Ice Age (LPIA) represents one of the most extreme climate transformations in Earth history, transitioning from icehouse to greenhouse conditions (e.g., [1], [2], [3], [4], [5], [6]). This climate amelioration is well documented in the sedimentological, palaeontological and geochemical record across Gondwana with Late Carboniferous and Permian basins of Australia, Antarctica, South America, Arabia, India and Africa representing excellent geological archives.

However, the controversial discussion on the termination of glaciation demonstrates the need for a more robust stratigraphic control including climatic palynoevents calibrated by radiometric data ([7]). From this background and building on previously postulated deglaciation models (e.g., [8], [9], [10], [11], [12], [13], [14], [15], [16]), the detailed study of vegetational changes recorded in palynomorph assemblages is seen as powerful tool to establish a refined biotic deglaciation model. Organic-rich shales and coal deposits from Sub-Saharan Karoo basins yield diverse palynomorph assemblages and are here used to better understand the timing of deglaciation. Furthermore, the high Total Organic Carbon content of organic-rich lake deposits makes them potential source rock targets for oil and gas.
Fig. 1. Palynomorph ranges and age determination of Permian black shales (Ecca Pass section, borehole KWV-1) and coal deposits (borehole BHS14) of the Main Karoo Basin, South Africa and Moatize Basin (borehole 945L_0022), Mozambique. Location of the studied boreholes: KWV-1 (Willowvale, Eastern Cape, South Africa), BHS14 (Witbank Coalfield, South Africa), 945L_0022 (Moatize Basin, Mozambique). Radiometric ages are available for the base of the Prince Albert Formation (marked by star, 288±3 Ma), and the lowermost Collingham Formation (marked by star, 268±3.2 Ma). The lake deposits identified in boreholes BHS14 and 945L_0022 document the final glacial retreat with melt waters supplying broad lowland sinks and have been assigned an Artinskian age based on palynology. They are correlated with the marine black shales of the lower Prince Albert Formation (Ecca Pass, borehole KWV-1) in the southern Main Karoo Basin.

Lake Deposits as Palaeoclimate Archives

New palynological data from Karoo basins of southwestern Gondwana (South Africa, Mozambique) reveal thick lacustrine deposits of Artinskian age ([17], [18], [19], [20]), documenting the final glacial retreat with melt waters supplying broad lowland sinks. This lake signature is well documented in the palynofacies of the interseam deposits of the No. 2 coal seam of the Main Karoo Basin and the carbonaceous siltstones between the Sousa Pinto and Chipanga seams in the Moatize Basin of Mozambique. The switch from cold to cool-temperate conditions is displayed in the pollen record with the first taeniate bisaccate elements occurring in the Artinskian, clearly marking a change in the upland flora. This prominent floral signature indicates that at least in the southwestern part of Gondwana glaciers still characterized the upland regions during the late Cisuralian. Palynological evidence of a prolonged glaciation also includes marine phytoplankton associations and their response on meltwater influx into the marine basin parts of the southern Main Karoo Basin during the late Cisuralian ([21]).
Melt water influx from the NE into the basin is documented by aquatic palynomorphs including freshwater algae such as *Tetraporina* and *Botryococcus*, prasinophytes such as *Cymatiosphaera*, as well as marine acritarchs (*Micrhystridium* spp.) occurring in the marginal and most proximal northern basin parts. By contrast, the phytoplankton assemblage of the southern, distal basin comprises prasinophytes and acritarchs, pointing to a deep stratified basinal setting.

**Chronostratigraphic Placement**

The studied outcrop and well sections (Fig. 1) span the late Cisuralian (Artinskian/Kungurian) and early Guadalupian (Roadian/Wordian). The Artinskian lake deposits of the Moatize Basin of Mozambique and the northeastern Main Karoo Basin of South Africa correspond to the lowermost marine black shales (Prince Albert Fm.) of the southern and western Main Karoo Basin. Radiometric ages from the Ecca Pass section were recently made available ([22]), assigning the Whitehill Formation a Roadian age. Previous works assigned the base of the underlying Prince Albert Formation an Artinskian age ([23]). These dates provide a tentative chronostratigraphic framework and support the Artinskian age of the lacustrine interval based on palynostratigraphy.

**Industrial Application**

The high Total Organic Carbon (TOC) content of the lacustrine sediments ranging from 6.5 to 12% make the Permian lake basins identified in South Africa and Mozambique targets for hydrocarbon exploration. The lateral extent and similar facies are key parameters for future exploration activities, mainly related to the recent hydrocarbon discoveries offshore Mozambique in the Rovuma Basin ([24]). In this context, outcrops along the Muaradzi and Moatize river sections represent valuable analogues with lacustrine deposits reaching thicknesses of tens of meters. These outcrops provide insights into the deepest, yet unpenetrated sections of the offshore rift basins along the southeastern margin of Africa. This information combined with the data gained from boreholes and regional correlation presented herein allow more refined interpretations on the source rock quality and overall petroleum system models from geophysical data.

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New Data on Pennsylvanian Conodonts from the North of the Russian Platform

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Abstract

The distribution of the middle and Upper Carboniferous conodonts of the Malaya Pokoyama reference section (right bank of the Volonga River, Northern Timan, Russia) is revised and new zonal biostratigraphic subdivisions are established. Correlation of the local lithological subdivisions with the regional stratigraphic scale of the Russian Platform is provided. It is shown that the sequence of conodont zones in the north of the Russian Platform is similar to that established in the sections of the southern regions of the basin, in the stratotype area for the Moscovian, Kasimovian and Gzhelian Stages. Six zones are established in the Moscovian, two zones – in the Kasimovian and one in the lower part of the Gzhelian.

Keywords: conodonts, Moscovian, Kasimovian, Gzhelian stages, Pennsylvanian, Northern Timan

Introduction

The Northern Timan is situated in a transitional zone between the stratotype region of the Carboniferous deposits of the central regions of the Russian Platform, Arctic province and the North American sections, and is characterized by the widespread development of Carboniferous carbonates. This is of great importance for global correlation. The first information about the Carboniferous conodonts of the western slope of the Northern Timan was published [1], [2], [3]. Recently new data on taxonomy of the conodonts have been obtained, new species have been described, their taxonomy and stratigraphic distribution have been updated, and the Middle and Upper Carboniferous conodont zones from type sections of the Moscow Basin and the South Urals have been detailed [4], [5]. Despite previous studies on Carboniferous stratigraphy, many problems remained unresolved regarding the dating of the boundaries of large stratigraphic units, the relationship of regional substages with a general stratigraphic scale, and the specifics of biozonal units, in particular for conodonts. This made it necessary to return to the revision of the conodonts of the Timan region, to reconsider the species composition of the conodont assemblages and to provide a new zonation.

Geological Setting

In the Late Paleozoic, the Northern Timan was part of a vast shallow-water epicontinental basin with predominantly carbonate sedimentation. Barkhatova [6] was the first to study the Carboniferous deposits and brachiopod assemblages of the Northern Timan. In the upper part of the Bashkirian, the Mador formation was recognized, in the Moscovian, the Volonga, II and Sula formations were established, in the Kasimovian, the Burkem and Odessa formations, and the Ayuva Formation at the base of the Gzhelian were identified. Later these formations were characterized by fusulinids [7], [8], [9]. The shallow-water Carboniferous deposits of the
western slope of the Timan Ridge are characterized by the alternation of clay, bioclastic limestone and dolomite beds. The most complete Malaya Pokoyama Section is located on the right bank of the Volonga River (Fig. 1). This section is represented by stratigraphic sequences from the Early Carboniferous to the Lower Permian Artinskian Stage. The Moscovian, Kasimovian and the lower part of the Gzhelian intervals are described bed by bed.

Material

The material for the study comprised 190 samples with a total weight of 200 kg, and 60% of samples contained conodont elements. In total, 700 elements were isolated, including 526 platform elements. The distribution of conodonts in the section, the correlation with lithostratigraphic units, and previous conodont zonation’s are shown in Fig. 2, 3. The specimens are housed in the Geological Institute, collection no. 945.

Results and Discussion

Moscovian Stage

Based on lithology, the Moscovian Stage in the Malaya Pokoyama Section (about 138 m thick in total) is subdivided into the Mador, Volonga, Il and Sula formations.

Mador Formation

The Mador Formation (Beds 38-54) is represented by bioclastic limestone with abundant red cherts in the lower part and dolomite in the upper part. The thickness is 27 m. Two zones were established. The lower part of the formation (Beds 38-39) contains *Neognathodus atokaensis* Grayson, *Declinognathodus marginodosus* (Grayson) and numerous *Idiognathoides*, and this interval can be considered as the *Neognathodus atokaensis* Zone and correlated with the Vereian Substage of the Moscow Basin. The *Neognathodus bothrops* Zone was established in the interval of Beds 40-54. The base of this zone is characterized by the first appearance of *Neognathodus bothrops* Merrill. This zone is characterized by *Neognathodus bothrops, N. tsnensis* Alekseev and Gerelzezeg, *Diplognathodus ellesmerensis* Bender, *D. coloradoensis* Murray and Chronic, *Idiognathodus izvaricus* Nemyrovska. Species of *Idiognathoides* continue into this interval, but *Idiognathoides* and *Declinognathodus* are absent in the Moscow Basin.

This zone corresponds to the Kashirian Substage of the type region. V.P. Barkhatova considered the Mador Formation to be Bashkirian, but conodont assemblages unequivocally
suggest this interval to be attributed to the Kashirian, and the upper part to the Vereian Substage of the Moscovian Stage.

Fig. 2. Distribution of Moscovian conodonts in the Malaya Pokoyama section. Explanations: (1) limestone; (2) dolomite; (3) argillaceous limestone (4) carbonate clay; (5) cavernous limestone; (6) cherts
Fig. 3. Distribution of the Kasimovian and Gzhelian conodonts in the Malaya Pokoyama section.
Volonga Formation

The formation (Beds 55-79 beds) is represented by bioclastic limestones, clayey limestone and marls. The thickness is 35 m. The Neognathodus medulimitus Zone is established (Beds 55-70). The medulimitus Zone is characterized by the co-occurrence of index-species with Idiognathodus izvaricus, I. obliquus Kossenko and Kozitskaya and some species of Idiognathoides. The specific character of the conodont distribution in Northern Timan is indicated by the wider range of the Idiognathoides species, as in the synchronous successions of the South Urals and the Canadian Arctic. This zone corresponds to the Kashirian Substage of the type region. Next, the Idiognathodus podolskensis Zone (Beds 71-91) is characteristic of the upper part of the Volonga Formation (Beds 71-79) and the lower part of the II Formation (Beds 80-91).

Il Formation

This formation (Beds 80-102) is represented by an alternation of limestone and dolomites. The thickness is 43.5 m. The II Formation corresponds to the upper part of Idiognathodus podolskensis (80-91 beds) and Neognathodus inaequalis zones (92-106 beds). This interval is correlated with Podolskian Substage of the Moscow Basin. As a whole the conodont assemblages of II Formation are impoverished than those of the Volonga Formation. Swadelina concinna (Kossenko) was recorded at the upper part of this zone (bed 82). The base of next zone, Neognathodus inaequalis, was established based on the appearance of the index species in Bed 92, therefore the interval of this zone is within Beds 92-105. Idiognathodus obliquus and I. podolskensis continue to occur in this interval.

Sula Formation

This formation (Beds 103-117) is represented by limestone with algae and dolomites. The conodont assemblages include Neognathodus roundyi (Gunnell), N. inaequalis Kozitskaya, rare N. dilatus (Stauffer and Plummer) and Gondolella sp. A typical characteristic of these assemblages is the base for correlation with the N. roundyi Zone of the Myachkovian Substage of the stratotype area.

Kasimovian Stage

This interval is subdivided into the Burkem and Odessa formations (about 138 m thick).

Burkem Formation

This formation is represented by dolomitized limestone (Beds 118-122), thickness 15 m, and do not contain platform elements of the conodonts. In the stratotype area is interval corresponds to the Krevyakinskian Substage and two conodont zones – Swadelina subexcelsa and Swadelina makhlinae.

Odessa Formation

The deposits are represented by limestone and dolomite (Beds 123-134), thickness 52 m. Conodonts are rare in the Odessa Formation, but their species composition allows two zones to be recognized. The lower boundary of the Idiognathodus sagittalis Zone is marked by the first appearance of Idiognathodus sagittalis (Kozitskaya) and I. neverovensis (Goreva and Alekseev). These species are known from Khamovnikian Substage of the Kasimovian in the Moscow Basin and Limestones N2-O2 in the Donets Basin. The base of the Idiognathodus toretzianus Zone was established by the occurrence of the index species at the base of bed 127. This species is typical of the Dorogomilovian Substage of the Moscow Basin. Idiognathodus lobulatus Kozitskaya and I. pawhuskaensis (Harris and Hollingsworth) occur in the upper part of this zone.
Gzhelian Stage

Ajuva Formation
This formation is represented by dolomites and limestones (Beds 135-155), thickness 55 m. The lower boundary of the Gzhel beds is fixed by a sharp change in the assemblage is the appearance of Idiognathodus simulator (Ellison), Id. tersus (Ellison), I. luganicus (Kozitskaya), etc., characterizing the base of the Gzhelian and corresponding to the simulator Zone. The overlying Streptognathodus vitali Zone, corresponding to the Noginskian Regional Substage of the central part of the Russian Platform, is established.

Conclusions
Detailed re-examination of the distribution of conodonts in the reference section allowed nine conodont zones to be delimited: (1) Neognathodus atokaensis Zone, (2) N. bothrops Zone, (3) N. medadultimus Zone, (4) Idiognathodus podolskensis – medexultimus Zone, (5) N. inaequalis Zone and (6) N. roundyi Zone were established in the Moscovian; (7) Idiognathodus sagittalis Zone, (8) I. toretzianus Zone were established in the Kasimovian and (9) Idiognathus simulator zone was established at the base of the Gzhelian. The local subdivision was correlated with the regional stratigraphic scale of the Russian Platform.

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REFERENCES
Geochemical Aspects of the Romashkino Oil Field (Based on the Berezovskaya Area)

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Abstract

This paper is a geochemical study of the oil formation located in the South Tatar Arch and its possible generation sources. The reconstruction of the initial organic matter, the facial conditions of accumulation and the degree of catagenetic maturity based on the redistribution of biomarkers in oil and bitumoid from rocks of different aged deposits of the Berezovskaya area of the Romashkino oil field was carried out and compared with the results of other authors.

A connection between the organic matter of the Domanic formation and the oil and bitumen from the sediments of the same age was found, and the differences in their composition were shown. The relationship between the bitumen and oil of the productive Devonian terrigenous rocks was evaluated based on their components and biomarker composition. The similar reducing depositional settings indicate the presence of a deep fluid component in the formation of the oil-bearing strata in the Berezovskaya area of the Romashkino Oil Field.

Keywords: oil, organic matter, composition, biomarkers, genesis, crystalline basement, Domanic Formation

Introduction

The Volga-Ural petroleum province, particularly of Tatarstan territory, has been intensively explored. However, the origin of the oil in the South Tatar Arch (STA) and adjacent territories remains extremely debatable [1]. Regardless of the fact that the Domanic Formation is demonstrated highly productive oil-bearing stratum for most deposits in the overlying carbonate sediments of the Volga-Ural Basin [2], [3], [4], [5], for the large Devonian deposits this statement raises certain doubts. A publication [6] excludes the possibility of migration of hydrocarbons (HC) from the Pre-Urals Foredeep and the Caspian Depression. The calculation of the synthetic HC of Devonian deposits showed that their greatest amounts are concentrated in the ancient depressions flanking the largest oil deposits in the STA and their initial amount was quite sufficient for the formation of oil deposits in the territory of the Volga-Ural Basin, even with a relatively low accumulation coefficient. A publication [7] claims that the oil-bearing strata are terrigenous deposits of the Timanian and Pashian horizons of the Buzuluk Depression, as well as clayey terrigenous rocks of the underlying horizons. However, they contain much less organic matter (OM) than the deposits of the Domanic Formation. Among other ideas, the possibility of HC coming from the basement is also discussed [1], [8]. Interest in the crystalline basement is due to the fact that according to some data [9] it may contain oil deposits; moreover, faults in the basement may serve as migration routes for HC to the overlying sediments. The possibility of the ongoing replenishment of the oil-bearing complexes in the STA with HC from the basement rocks has been also proposed [10].
The purpose of this study was a geochemical analysis of the oil formation in the STA and its possible generation sources, by reconstructing the original type and facies conditions of accumulation of OM, determining the degree of its catagenetic maturity and detecting secondary migration processes.

**Methodology**

The objects of this research were crude oil samples and cores from Devonian (D₃sm and D₃mnd, D₃tm, D₃ps, D₂zv) deposits of the Berezovskaya area of the Romashkino Oil Field, as well as core samples from the basement rocks in this deposit (Fig. 1, table). A particular focus is made on this territory, as the Berezovskaya area adjoins the Altunino-Shunaksky Depression, which separates the two largest deposits of the Volga-Ural oil and gas basin. At the base of this depression there is a large tectonic fault developed in the crystalline basement. The relief of the crystalline basement has a complex block structure, which is complicated by north-east- and north-west-striking faults. During the oil formation the crystalline basement could repeatedly become a permeable zone during periods of tectonic activation [1], [8], [9].

Bitumoids were extracted from core samples on the Soxhlet instrument using a mixture of solvents containing chloroform, benzene and isopropyl alcohol in equal proportions.

Determination of the bitumoid and oil composition was carried out by column liquid-adsorption chromatography on ASG silica gel with the separation of the hydrocarbon part (oils) and two groups of resins: benzene and alcohol-benzene. Before adsorption separation from the bitumoids and oil, asphaltenes were precipitated in 40-multiple hexane according to a standard procedure.

![Fig. 1. Objects of investigation on the map of the Romashkino oil field: 1) Altunino-Shunaksky depression, 2) basement faults, 3) wells of oil sampling, 4) wells of core sampling](image)
Table 1. General characteristics of oils and bitumoids from rocks of the Berezovskaya area and of the Romashkino Oil Field crystalline basement

<table>
<thead>
<tr>
<th>№</th>
<th>Area</th>
<th>Geological age</th>
<th>Sampling interval, m</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Berezovskaya</td>
<td>D₃sm</td>
<td>1769-1773</td>
<td>Carbonate</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>D₃ sm</td>
<td>1808-1826.6</td>
<td>Carbonate</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>D₃ tm</td>
<td>1780.3-1782.2</td>
<td>Sandstone</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>D₃ tm + ps</td>
<td>1763.2-1765.2, 1766.0-1767.6</td>
<td>Sandstone</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>D₃ ps</td>
<td>1832.1-1839.6</td>
<td>Sandstone</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>D₂ Zv</td>
<td>1803.8-1806.0</td>
<td>Sandstone</td>
</tr>
</tbody>
</table>

**Bitumen extracted from sedimentary rocks**

| 7  | Berezovskaya     | D₃sm           | 1759.0-1760.5        | Marlstone       |
| 8  |                  | D₃sm           | 1805-1808            | Carbonate       |
| 9  |                  | D₃ps           | 1761.0-1762.6        | Sandstone       |
| 10 |                  | D₃ps           | 1766.8-1770.0        | Argillite       |
| 11 |                  | D₃ps           | 1852-1860            | Sandstone       |
| 12 |                  | D₂Zv           | 1869-1876            | Sandstone       |

**Bitumen extracted from crystalline basement rocks**

| 13 | Alkeevskaya      | AR-PR          | 1809.5-1810.0        | Gneissose granite |
| 14 | Almetevskaya     | AR-PR          | 1827.0-1827.8        | Gneissose granite |
| 15 | Pavlovskaya      | AR-PR          | 1838.0-1838.6        | Gneissose granite |
| 16 | Abdrakhmanovskaya| AR-PR          | 1886.0-1886.8        | Gneissose granite |
| 17 | Zelenogorskaya   | AR-PR          | 1936.2-1937.0        | Gneissose granite |

The individual hydrocarbon composition of bitumoids and oils was studied by chromatography-mass spectrometry using a DFS Thermo Electron Corporation (Germany).

The energy of the ionizing electrons was 70 eV; the temperature of the ion source was 280 °C. A helium capillary column; length 50 m; diameter 0.32 mm was used. The ID-BP5X (equivalent to DB-5MS) stationary phase thickness 0.25 μm. Chromatography was carried out in a linear temperature programming mode: from 60 to 280 °C with a temperature rise rate of 10 °C/min. Mass spectrometric recording was performed using the total ion current (TIC), in the selective monitoring mode, recording mass-fragmentograms for characteristic ions m/z 71 (n-alkanes), m/z 191, 177 (gopans) and m/z 217, 218 (sterans). The results were processed in the TurboChrom/Geochemistry Navigator system. The identification of hydrocarbons was carried out using literature and library data.

**Results and Discussion**

The studied oils and bitumen from the rocks of various productive complexes of the Berezovskaya area are heterogeneous in their composition. Some features of their composition were revealed: the oils from the Domanic deposits are quite close in composition to the oil from the terrigenous Devonian beds, but both differ significantly by the chloroform bitumen A (CBA) content from the bitumoids of sedimentary and basement rocks. The oils are characterized by a high content of hydrocarbon compounds (61-78 wt %), low resin content (20-37 wt %) and very low content of asphaltenes (less than 5%). Bitumoids contain 1.5-3 times less hydrocarbon compounds, but 2-3 times more asphaltenes. The bitumoids of the Domanic
formation contain 53 wt % of asphaltenes. Note that the compositions of bitumen from the terrigenous Devonian deposits and basement were similar.

To interpret the origin, gas-chromatographic coefficients commonly used in geochemical studies, which are the ratio of pristane/phytane (Pr/Ph), Pr/n-C₁₇ and Ph/n-C₁₈, were applied to assess the redox environment in early diagenesis and the catagenetic and migration processes at subsequent stages of deposit formation [11], [12]. In addition, the study involved examination of the indicators reflecting the nature of higher polycyclic biomarkers, i.e., steranes and terpanes.

Chromatofossils are widely used as correlation parameters for revealing the source of OM, the facial conditions of deposition, for determining the diagenesis conditions, the degree of catagenetic transformation and maturity of the OM of the oil-bearing stratum [11], [12], [13].

In terms of the parameters Pr/n-C₁₇ and Ph/n-C₁₈ (Connan-Cassou diagram), all samples of oils and bitumoids fall into the region of strongly reducing shallow marine sedimentation environments of OM, and are mature judging from their catagenetic transformation. Bitumoids from the rocks of the crystalline basement fall into the post-ripe zone (Fig. 3). The Pr/Ph (0.3-0.77) values of oils and bitumoids of the Devonian series indicate the marine origin of the initial OM under strongly reducing conditions. The Pr/Ph ratio for the basement bitumoids shows somewhat larger values (0.8-1.03).

Fig. 3. Relative distribution of Pr/n-C₁₇ and Ph/n-C₁₈

Geochemical parameters indicative of the source of OM and the conditions of its deposition include C₂₇, C₂₈, C₂₉-steranes. A high proportion of C₂₇-steranes indicates OM associated with plankton, whereas the predominance of C₂₉-steranes is due to the participation of higher-plant lipids, so the composition of steranes can be used to identify sources of organic matter [14], [15], [16]. The investigated fluids contain from 32 to 47% C₂₇-sterane, from 28 to 44% C₂₉-sterane and from 16 to 26% C₂₈-sterane, which indicates a predominance of sapropelic material (algae and bacteria) in the initial OM with a significant admixture of humic organics. That is, in terms of the relative content of C₂₇, C₂₈ and C₂₉-steranes, shown as a triangular diagram (Fig. 4), one or another type of generating formation cannot be clearly distinguished. However, it is important to note that the terrigenous Devonian oil falls into the region of mixed humus-sapropelic OM, while the Domanic oil and bitumen are closer to the area of pure sapropelic
OM. The ratio of steranes C\textsubscript{28}/C\textsubscript{29}=0.55 indicates that the deposition of the sediment with the initial OM occurred in the Devonian.

![Ternary diagram of 20R-steranes (C\textsubscript{27}, C\textsubscript{28}, C\textsubscript{29}): I – land plants, II – planktonic/land plants, III – planktonic/algal, IV – planktonic/bacterial, V – diatoms/bryophytes]

The objects investigated for the DIA/REG parameters and T\textsubscript{s}/T\textsubscript{m} are conditionally divided into two groups. The values of these parameters for the fluids of the Domanic deposits indicate their connection with carbonate basins, while the origin of the bitumoids from the basement rocks and some of the bitumoid samples from the terrigenous Pashian deposits is associated with clay minerals. This is because the regrouped steranes are mainly formed in clay deposits.

However, the separation into two groups is not sufficiently clear, allowing us to distinguish in [1] an intermediate group with ambiguous parameters at the Romashkino Oil Field.

According to the authors of [1], this indicates a mixed type of oil due to the processes of ascending and descending migration. The results of the conducted studies indicate that similar processes took place during the formation of the oil presence in the territory of the Berezovskaya area located in the zone of development of major tectonic basement faults. In this area, some oils and bitumoids from the rocks of regionally productive deposits of the Pashian horizon can be assigned to the intermediate group.

**Conclusions**

The examined oil of the Semiluki horizon is syngentic to the host sediments. The deposits of the Semiluki horizon in the territory of the STA are at the stage of late protocatagenesis, with the transition to the early stages of mesocatalagenesis [17]. According to Bazhenova [18], kerogen-rich silicic-carbonate deposits are already capable at this stage of generating “immature” oil. The low degree of maturity of the fluids of the Domanic formations is confirmed by the values of the geochemical parameters considered in the study.

Oil-bearing rocks were formed in highly reducing marine conditions. The source of organic matter was marine microorganisms (algae and bacteria), as well as considerable quantities of the remains of higher plants. The latter is especially characteristic for terrigenous Devonian oil and bitumoids.

The close values of the geochemical parameters for the terrigenous Devonian and the crystalline basement oils and bitumoids, and their difference from similar parameters for the Domanic formation oils and bitumoids, indicate the various sources of their generation. The
values of the indicators: Pr/Ph, DIA/REG and T_s/T_m, indicate the relationship of the basement bitumoids with the fluids from terrigenous deposits. The possibility of the existence of several sources of oil generation differing in the lithological composition of the oil-bearing rocks was indicated in [7]. The data given in [1], according to which carbonate and terrigenous petroleum rocks took part in the generation of oil of Pashian and Timanian productive beds, were confirmed.

Thus, the differences in the composition of petroleum and bitumen of the Domanic formations compared to the oils of sub-Domanic sediments and basement bitumen were revealed. The similar component and biomarker composition of bitumen from the basement rocks and the terrigenous Devonian stratum is shown, and a similarity of the reducing conditions during their deposition is revealed, which indicates the influence of crystalline base fluids on the formation of the oil-bearing capacity of the Berezovskaya area.

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REFERENCES
Seismostratigraphic Analysis of a Carbonate Section Located in the Territory of the South-Tatarian Asch

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Abstract

This article describes a seismic-stratigraphic analysis technique for carbonate sections. Starting with a seismic-to-well tie using VSP and well logging data, it is possible to determine both the structural interpretation of the seismic 3D cube, and the allocation of sequences. It is further possible to calculate seismic attributes, and build paleosurfaces, by adding to the track relative seismic shifts, and finishing with the allocation of seismic facies in the area and forecast of zones with improved reservoir properties.

In the Tatarstan Republic’s sedimentary cover, carbonate sediments contain huge amounts of hydrocarbons. Thus, the carbonate cover is an object of necessary study [6]. Carbonate rocks can be both reservoir and non-reservoir, therefore the main objective of the seismic-stratigraphic analysis is the allocation of zones with improved reservoir properties – potential traps for hydrocarbons [10].

The seismic-stratigraphic analysis was carried out by 3D seismic data within the oilfield of the southeast slope of the South-Tatarian arch. Sedimentary cover of the area consists of several systems: the Devonian, Carboniferous, Permian, Neogene and Quarternary.

Keywords: Seismic survey, attribute analysis, seismic facies

Introduction

Seismic-stratigraphic analysis technique for carbonate sections allows obtaining new information on the facies, located in the oilfield. By deep analysis on the seismic attributes with the geological understanding of the depositional system gives it is possible to obtain facies distribution in the carbonate section.

Methodology

Structural interpretation of a seismic cube was carried out. The simple velocity model was used to create structural maps, geological pseudo-deep sections, and for calculating the paleosurfaces for each allocated horizon.

There are three seismic attributes (Schlumberger Petrel development): Local Structural Dip, Chaos, and Cosine of Phase. The latter was used for the reliable identification of facies [3], [8], [9]. The “Local structural dip attribute” calculates a local inclination of the reflection in the field of attribute calculation [9]. This attribute can also be used to determine the non-uniform areas (with local corner changes) and quiet areas (with a constant corner). The “Chaos” attribute corresponds to an absence of organization in the seismic record. This attribute defines how consistently accurate the estimated orientation of an inclination and azimuth is when using the method of the main component [8]. Estimated measurements with a low coherence correspond
to a chaotic signal. The “Chaos” attribute is used to determine the breaks, salt bodies and reflectors with a chaotic texture which often are associated with paleochannels or reefs. Another important characteristic of the attribute is the fact that it does not vary with amplitude and orientation. Therefore, it will show the coordinated results in areas with high or low amplitudes and also oblique reflections. The cosine of the instantaneous phase is a cosine of the instantaneous phase angle ($\phi$). Amplitude peaks remain in the same position, but the strong and weak reflections will have the same amplitude [8]. The cosine of the instantaneous phase improves the possibility of horizon tracing and improves visual appearance of a seismic section.

This seismic attribute allows the tracing of faults, pinchouts and other stratigraphically events.

When making an analysis, seismic complexes which reflect natural change of lithology on the section were marked. Paleogeomorphological and seismic facies analysis allowed the identification of tectonic modes during accumulation of sediments and the related sedimentation cycle. The result of executed interpretations of wave fields is an allocation of sequences that were identified according to eustatic events in the period of sedimentation (Fig. 1).

![Fig. 1. Method of making of the seismic-stratigraphic analysis. Structural interpretation → paleo relief → calculation of attributes (Chaos, Local Structural DIP, Cosine of Phase) → allocation of facies](image-url)
Results

Several seismic complexes which reflect the natural change of lithology of the section were marked. The paleogeomorphological and seismic facies analysis allowed identification of the tectonic modes during the accumulation of sediments and the related cycle of sedimentation.

The interpretation result is an allocation of sequences which are connected to eustatic events during the sedimentation.

**Sequence A.** Conditionally includes sediments from Sargaian horizon. Reflections of upper Timanian horizon sediments were determined in the composition of the sequence.

**Sequences B and C** were considered as a combined sequence B-C because Semilukian and Mendymian sediments reflect these sequences together.

In the southeast and east part of the research area an increase of thickness was observed.

This, most likely, indicates the formation of algal bioherms in the Mendymian stage in the region of “the Sargaian-Semilukian hardground”. Bioherms of the Mendymian stage were formed where Domanikovian and even Sargaian sediments consist of shallow marine facies. In separate time intervals marine conditions were replaced by lagoon conditions.

**Sequence D** corresponds to Voronezhian-Evlanian-Livenian sediments (Upper Frasnian time). The conditions of the shelf plain and a carbonate shoal were in the research area in the Voronezhian-Evlanian-Livenian stage. There is a calcareous and dolomitic raised construction in the zones with the Mendymian algal bioherm in the Voronezhian stage [1], [2], [3], [5]. There was a calcareous accumulation between bioherms.

**Sequence E** corresponds to sediments of the Zadonian-Yeleckian horizon of the Lower Famennian stage. The thickness of a Lower Famennian complex can reach 200 meters. There was the shelf slope with mainly marine conditions with normal salinity and gas mode of water.

This section of the wave field indicates progradational clinothem (Fig. 2). According to classical representations of carbonate sedimentation, it is possible to predict the following sediments in a clinothem: accumulated in the bottom zone of every parasequence there is short-grained, partially siliceous limestone [2].

![Fig. 2. 3D model of paleo relief on a moment of clinothem forming Zadonian-Yeleckian stage](image-url)
Sequence F corresponds to Dankovian-Lebedyanskian (the middle Famennian stage) sediments which on the separated areas lie with unconformity on the underlying layer of a Frasnian stage. Possible biostromal forms of organogenic constructions were highlighted on the paleo structural maps.

Sequence G corresponds to sediments of the Zavolzhian horizon which, in general, is characterised by marine sedimentation conditions. The research area was located in the deeper part of shallow shelf. The gray, light gray, fine-grained limestones, dolomitic and almost turned to dolomite were accumulated here [2]. Calcareous buildings of algal slime were formed in places of organogenic buildings of the Upper Frasnian and Lower Famennian time.

Sequence H consists of Malevskian-Upinskian sediments of the Tournaisian stage. There was an epicontinental sea basin in the territory of the Volga-Ural oil-and-gas province in the Tournaisian time. There were four lithological facial zones: coastal sediments, shallow shelf, deep-water sediments, which were related to axial parts of troughs, and the shallow water sediments which were related to the onboard parts of the Kama-Kinel system of troughs [2], [4], [5], [7] (Fig. 3).

![3D model of paleo relief of the end of the Malevskian-Upinskian time](image_url)
Discussion

The known methods of seismic stratigraphy are based on the construction of Wheeler lattices, and on the allocation of parasequences pointing to the system path. The system path provides the ability to predict facies and lithology. This approach is effective in the study of large areas, regional seismic profiles, etc. The technique described above proposes using paleomorphological (paleostructural) analysis of reflected surfaces, attribute wave field analysis to locate seismic facies and further predict facies and sediments. However, such studies can be carried out based on a systems approach, using information of both the regional and the local level.

The lithological description of drilled wells confirms the findings of the sequences based on seismic stratigraphic analysis.

Conclusion

Thus, through interpretation of the wave field (the seismic-stratigraphic analysis), and by considering eustatic events, the sedimentation model was created.

The received sedimentation model by means of a paleoreconstruction revealed the existence of weakened zones during various periods of sedimentation of the basin, along with possible fractured zones in the carbonate.

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REFERENCES

Use of an Optical Scanning Device for Complex Core Analysis

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Abstract

Photography is one of the conventional tools used for studying core samples. Images taken in visible and ultraviolet light are used for record-keeping, lithological description and identification of bitumen saturated intervals. However, this method’s potential is far greater.

This paper presents an innovative optical core scanner and outlines its key applications. Basic technical characteristics and modes of the scanner are described along with specific approaches to processing the scan data. The study results obtained with the scanner are compared with the outcomes of conventional petrophysical methods. The benefits of optical scanning in various modes (which are difficult to achieve when using any other research technologies) are also shown.

Introduction

At present, new tools and methods for studying the whole core are being intensively developed. Preference is given to non-destructive methods delivering as much information about the core as possible. These methods include X-ray CT [1], the study of natural radioactivity in core samples [2], nuclear magnetic resonance (NMR) spectroscopy [3], [4] and others. However, these methods are costly and time-consuming. Instead, UV photography can be applied to the study of core samples. Usually, the photographs are used for record-keeping, lithological description and identification of hydrocarbon saturated intervals [2], but their use can be significantly expanded with advanced scanning and processing techniques.

This paper presents an innovative optical core scanner. Basic technical characteristics and operating modes of the scanner are described in detail along with specific approaches to the scan data processing and examples of several geological problems that can be solved using the scanner.

Design and Function of the Core Scanner

The SKIF optical core scanner is a laboratory setup designed for studying core samples of any diameter in ultraviolet and visible light. The scanner is built up from the following elements: 1) aluminium body and rollers; 2) camera movement system; 3) backlight (various spectral ranges) system (Fig. 1). A zero-backlash gearbox is used for core rotation to prevent core displacement and slipping.

The cameras are moved by stepper motors. Stepper motor drivers are operated by a controller which is also responsible for data exchange with the computer (via Ethernet) and backlight control. Special computer software synchronizes the work of the whole setup.

The most important part of the scanner is the high-precision slider camera movement system.

The movement rate (up to 10 m/min) provides high imaging efficiency. The camera positioning accuracy is 0.01 mm, which results in images with a resolution of 30-40 microns.
The multi-point illumination system together with light reflectors and diffusers prevents the appearance of shadow zones and ensures colour reproduction, which is important when correlating core samples taken from different wells. UV light reveals the core sections saturated with hydrocarbons.

![General view of the scanner](image)

The following operating modes are available:

1. **Photographing a core box/tray.** First, the core box (dimensions must not exceed 600*1100 mm) is put under the cameras. Next, the cameras move along predetermined paths and take a series of images with 60% overlap. The photographs are then combined into a single image of given resolution.

2. **Photographing with rotating rollers.** In this case, the images are taken while the core is rotating around its long axis. This mode allows the study of several core samples (total length must not exceed 1100 mm) at once, and delivers data suitable for various purposes:
   - 2D image reconstruction (texture of the core surface, unwrapped).
   - Reconstruction of the 3D geometry, including surface microrelief (photogrammetry).

Each operating mode uses specific camera/lighting type:

1. **Full-colour image taken in natural light with RGB camera.**
2. **UV (365 nm) monochrome image taken with wide range camera and a filter that does not pass visible light.**
3. **Full-colour fluorescence image taken with RGB camera in 365 nm backlight.**

**Methodology of Data Processing**

The initial data is a set of photographs taken in various modes without any colour or lens correction. To create the resulting image, photogrammetric bundle adjustment is carried out.

Photogrammetry encompasses methods of image measurement and interpretation in order to derive the shape and location of an object from one or more photographs of that object [5]. This procedure is carried out in several steps:

1. **Corrections are introduced to eliminate all distortions.** The width, length and center point of the frame are determined. These parameters are called elements of interior orientation. In close range photogrammetry, these parameters, as a rule, are not constants and are rectified during other stages of the adjustment procedure.

2. **For each image, the position of the center point is defined in the coordinate space of the setup.** These parameters are called elements of exterior orientation.
3. Characteristic points – small areas of the image, which are easily distinguished by computer vision – are identified.

4. All characteristic points in all images are compared with each other in order to find neighbouring pairs of images. In our case, there is no need to search for matches in every single image since the elements of exterior orientation are already known. Instead, only neighbouring frames are examined, which greatly speeds up the adjustment procedure. This step is called preselection.

5. Taking into account the elements of external orientation, characteristic points that have matches (projections) on different images are used to rectify the elements of internal orientation and reconstruct the position of the frames relative to each other. This results in a dispersed point cloud that corresponds to the characteristic points in the photographs.

6. Each point of the dispersed point cloud has statistical characteristics, such as positioning error, the number of projections, etc. Based on these characteristics, the dispersed point cloud is filtered and the elements of interior orientation are rectified once again.

7. Finally, the dense point cloud and 3D geometry of the photographed object (core box or core sample) are reconstructed.

The 3D model obtained by photogrammetric processing is necessary for orthorectification. Orthorectification is a procedure that removes distortions from the image, creating an orthoimage with features positioned as they would be in a planimetric map [6]. Orthoimage is a georeferenced image prepared from a perspective photograph or other remotely-sensed data in which displacement of objects due to sensor orientation and terrain relief have been removed [7].

Orthorectification results in a photograph of a core box or a sample’s texture. It is also possible to obtain a 3D solid model of a core sample (i.e. its microrelief) in the process.

Results and Discussion

The result of the core studies are two-dimensional texture images and three-dimensional core models. They are digital copies of the core, i.e., they feature highly detailed surface relief and can be used to solve a wide range of geological problems.

Photographic documentation of the core

Photo documentation is a mandatory procedure capturing the core in its original state.

Photographs are used in the lithological description of the core. Often, there is a lack of due attention to this procedure (phone cameras or any other low-resolution cameras are used). As a result, the obtained images are noisy, of poor quality and resolution.

The core scanner presented in this paper can deliver images with different (predefined) resolutions. The resulting photographs have specified cell size, coordinate system and scale, file format and georeferenced type. This made it possible to estimate the linear dimensions of objects in the image: fractures, cavities, inclusions, interlayers, etc. Such images eliminate the ambiguity of the lithological description, and can also be used for quantitative evaluation of several structural features (fracture opening, grain size, thickness of interlayers, etc.).

Precise positioning system, identical camera paths and simultaneous processing ensure that images obtained in different spectrum ranges have the same spatial reference. The UV images complement the photographs taken in visible light and provide the basis for comprehensive lithological analysis and further detailed analysis of the fluorescence images. Figure 2 presents two photographs of a core box taken under different illuminations (visible and ultraviolet). On the right, there are enlarged fragments of the images. Secondary processes (inclusions of
anhydrite in limestone) and changes in lithotypes are clearly observed in the UV image. Thus, UV images reveal some texture features that cannot be properly seen in visible light.

**Grain size analysis**

Many characteristics of a porous medium (permeability, porosity, specific surface, capillary properties, etc.) depend on the grain composition. Usually, the grain composition is determined by screen test and sedimentation analysis. Screen test is used for >0.05 mm sand fractions. The content of smaller particles is determined by sedimentation analysis. For most petroleum rocks, the size of the rock-forming particles ranges from 1 to 0.01 mm. The core scanner has a spatial resolution of 30 microns, so there is a possibility to use machine vision for grain size analysis over the entire sampling interval.

![Fig. 2. Photographs of a core box](image)

**Core saturation analysis**

Usually, UV photographs are used to identify bitumen saturated intervals in the core. Moreover, this procedure is nearly always performed only at the qualitative level. For the quantitative assessment, 3-4 standard samples are taken per meter of the core. Next, for each sample, the bitumen saturation is determined by the extractive method. This approach may take up to several weeks, depending on the pore volume structure. Thus, classical methods are time consuming and the data are discretely distributed along the wellbore.

Identification of the intervals saturated with bitumen and quantitative assessment of the hydrocarbon content are possible with the combined processing of UV photographs and fluorescence images (through the mathematical spectral analysis [12]). The hydrocarbon content is estimated using the following empirically derived formula:

\[
B = \left\{ n \in \left\{ r \in \frac{FR - UV}{FR + UV} \mid r > 0 \right\} \ast 2 - \left\{ g \in \frac{FG - UV}{FG + UV} \mid g > 0 \right\} \mid n > 0 \right\}
\]

where, \( B \) is the raster representing bitumen content in the range of 0-1, \( FR \) is the red fluorescence channel, \( FG \) is the green fluorescence channel, \( UV \) is the UV channel.

The physical meaning of this formula is simple. It shows the spectrum range with maximum bitumen saturation.
Surface microrelief analysis

Photogrammetry can help to obtain highly detailed microrelief of the core surface (Fig. 3). The figure shows the microrelief (in the lower part) and the microrelief with texture overlay (in the upper part).

Fig. 3. An example of a 3D core model

Various GIS analysis techniques can be used in further processing:
- Local depression analysis [11] for optical porosity evaluation [8];
- Lineament and fracture analysis [10];
- A combination of the above methods for cavern porosity evaluation.

Analysis of core surface and texture can be applied to various geological problems. One of these tasks is the spatial orientation of the core. This becomes possible when comparing the results of photo scanning with the acoustic micro imaging data [13].

Conclusions

The optical core scanner, together with the specific set of methods and algorithms for image processing, increases the amount of geological information obtained in the initial stages of core studies.

3D solid models are digital copies of core samples, which means that they are available for study from anywhere in the world. It is worth mentioning that storage and transportation of core is an expensive operation. In contrast, digital core images can be stored on any electronic media and studied by several users at a time.

Digital core analysis seems to be underestimated. Modern image processing techniques and surface relief analysis allow the most efficient use of the core material.

Acknowledgements

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The Upscaling Effect in Permian and Devonian Sandstones Using the Buoyancy Method and Helium Porosimetry Method

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Abstract

This paper deals with the concept of representative elementary volume for Permian and Devonian sandstones. Various methodologies of evaluation of representative elementary volume are analysed. The effective approach for calculation of representative sizes of investigated core samples while using the buoyancy method and the helium porosimetry method was applied. The relationship between volume value of any core sample and deviation of open porosity ratio from average value for every core volume has been determined.

Keywords: representative elementary volume, open porosity ratio, core plug, upscaling, full-diameter core

Introduction

The relevance of this problem is explained by the fact that open porosity ratio mostly depends on the sizes of core samples, even if they were extracted from the same depth. This phenomenon is called upscaling. The effect of upscaling has a significant influence on the estimation of oil and gas reserves during routine core analysis in laboratories because adopted values for the diameter of core plugs are equal to 2.54 cm or 3.8 cm while the length of core plugs is 6.4 cm [1]. Heterogeneous core plugs having such sizes are probably not representative core samples. Consequently, values of reservoir properties may be incorrect. Furthermore, upscaling has a significant impact on the correlation analysis of reservoir properties evaluated by routine core analysis compared with the values obtained by borehole geophysical methods.

The research problem is extensively described in literature. The most widespread method presented in these studies is X-ray computed tomography with theoretical analysis of terms being given. Some of these issues are discussed below.

The term “representative elementary volume” for porous media was thoroughly studied by Bear [2]. Using the continuum approach to investigate porous media, Bear put a mathematical point P in a domain packed with porous medium having a spherical form. Obviously, porous media consists of solid phase (matrix) and void space. Bear marked the volume of porous media as ΔUᵢ, the volume of void space as (ΔUᵥᵢ)ᵢ with i=1,2,3…n. According to the definition of porosity ratio, marked as η, it is equal to the ratio of the volume of void space to the volume of porous media. Having investigated an increase of the volume of porous media from volume of mathematical point P that can be marked as ΔU₀ to volume of sphere marked as ΔU₁ and characterized by fixed radius, a graph presenting the fluctuation of porosity ratio was plotted. In the article, the volume marked as ΔU₀ shows the start of a stable interval. This volume is called representative elementary volume.

S. Claes, A. Foubert, J. Soete, M. Ozkül, R. Swennen studied the given problem analyzing the effect of upscaling in complex carbonates while using CT scans [3]. At the first stage three faces (front, side, top) of parallelepipidal reed lithology travertines and three faces (front, side, top) of parallelepipidal flat pool lithology travertines were investigated using photogrammetry.
Then three large cores 15 cm long by 10 cm in diameter were drilled out from both lithology parallelepipedic travertines, small plugs 4 cm long by 2 cm in diameter were extracted from large cores, micro-plugs 1.5 cm long by 0.7 cm in diameter were drilled out from small plugs. All the core samples were investigated while using various CT scanners characterized by various voxel resolutions in the resulting 3D datasets. During experiments the authors concluded that void ratios of larger core samples outnumber void ratios of smaller core samples of the same lithology, so it is essential to investigate core samples of different sizes recovered from the same rocks while using various resolutions to make reliable calculations of the representative elementary volume.

Mark A. Anderson, Brent Duncan, Ryan McLin studied the main aspects of routine core analysis providing essential information for evaluation of oil and gas reservoirs [1]. There are various types of cores of various sizes, for example, whole cores, sidewall cores, core plugs. Their sizes have an influence on the result of petrophysical measurements [4]. It is considered that core plugs are representative core samples characterizing whole cores if investigated rock samples are relatively homogeneous. In this case, core plugs are extracted at 1-ft (0.3-m) intervals along the length of the whole core segment. According to the authors, it is essential to extract core plugs at smaller intervals to investigate heterogeneous rocks or use the whole core to analyse highly heterogeneous rocks [5]. Obviously, a representative sample characterizing, for example, the whole core 3 ft long provides correct values of porosity.

B. Prilous studied this problem, analysing the principles of the theory of structured continuum [6]. Prilous used the theoretical analysis to investigate the porous media having spherical form that was essential to average the forces on the surface of this sphere. There are two theses of theory of structured continuum that allow the size of this sphere to be defined [7], [8]. Having reviewed some works, Prilous indicates some contradictions to the theory of structured continuum in these studies that use microscale [9], [10]. Prilous suggests the best solution of the problem, that is, application of mesoscale that makes it possible to define the representative volume of porous medium.

**Objects**

The research has been done in two steps, each step including the study of core samples of different diameters (Table 1).

**Table 1. Brief information on investigated cores**

<table>
<thead>
<tr>
<th>Step</th>
<th>Rock</th>
<th>Period</th>
<th>Core depth, m</th>
<th>Number of well</th>
<th>Field</th>
<th>Full-diameter cores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Length, cm</td>
</tr>
<tr>
<td>1</td>
<td>Sandstones</td>
<td>D</td>
<td>1693.1</td>
<td>4836</td>
<td>Tavelskoye</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P1u</td>
<td>228.1</td>
<td>34</td>
<td>Domoscikinskaya</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>204.3</td>
<td></td>
<td>area</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>205.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>213</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Devonian full-diameter core was recovered from water-bearing horizons some years ago, while four Permian full-diameter cores were recovered from the non-bitumen interval.
Methodology

The main point of the present study is to measure open porosity ratios of core samples from full-diameter cores to extracted core plugs 3 cm long by 3 cm diameter including core samples with various correlations of length and diameter. Open porosity ratios were evaluated by helium porosimetry and buoyancy methods [11], [12]. During laboratory measurements ratios of diameter to length for core samples extracted from full-diameter cores are 1:1, 1:2, 1:3.

At the first stage, open porosity ratios of Devonian full-diameter core and Permian full-diameter core recovered from a depth of 228.1 meters were calculated. Then two cylindrical core samples 6 cm long by 3 cm in diameter were drilled out from a full-diameter core and after investigating were divided into equal parts. Finally, after all the measurements were done, six core plugs 3 cm long by 3 cm in diameter were obtained.

During the second stage, open porosity ratios of three Permian full-diameter cores recovered from depths of 204.3, 205.5, 213 meters were estimated. Then two core samples 9 cm long by 3 cm in diameter were drilled out from every full-diameter core and after being studied were divided into two parts that are equal to a core 6 cm long by 3 cm in diameter (later divided into equal parts) and a core 3 cm long by 3 cm in diameter. All the samples were sequentially investigated. This algorithm was used for all three full-diameter cores.

Results

Results of measurements of open porosity ratios for investigated core samples are presented as relationships between open porosity ratio and volume value for Devonian (Fig. 1) and Permian (Fig. 2) sandstones. Volumes of core samples were calculated using parameters of lengths and diameters.

The first stage

The Permian full-diameter core recovered from the depth of 228.1 meters and the Devonian full-diameter core were investigated at this stage.

![Fig. 1. Relationship between open porosity ratio and volume value for the Devonian sandstone](image)
The relationship between open porosity ratio and volume value is presented only for the Devonian sandstone (Fig. 1) as some core samples extracted from the Permian full-diameter core had been crushed.

**The second stage**

Relationship between open porosity ratio and volume value is presented for three Permian full-diameter cores recovered from the depths of 204.3, 205.5, 213 meters (Fig. 2).

![Fig. 2. Relationship between open porosity ratio and volume value for three Permian full-diameter cores recovered from the depths of 204.3, 205.5, 213 meters](image)

Then maximum deviation of open porosity ratio from average value for every core volume was calculated. These calculated values for the Devonian sandstone are presented in this paper (Fig. 3).

![Fig. 3. Relationship between maximum deviation of open porosity ratio from average value and core volume for the Devonian sandstone](image)
Discussion

The regularity between maximum deviation of open porosity ratio from average value and core volume was revealed for each sandstone sample. This conformity is that decrease of volume of any investigated core sample results in the increase of maximum deviation of open porosity ratio from the average value. This growth of maximum deviations varies from 0.001\% to 6.201\%. The regularity is explained by the appearance of new connected pores during drilling out of core samples from full-diameter cores and dividing of bigger core samples into smaller core plugs.

Values of maximum deviations of open porosity ratios for the Devonian sandstone (Fig. 3) and for Permian sandstones were approximated with exponential functions. The parts of exponential functions that are defined with minimal fluctuations of maximum deviations of open porosity ratios were analysed, then representative elementary volumes were calculated for the all investigated sandstones (Table 2).

<table>
<thead>
<tr>
<th>Period</th>
<th>D</th>
<th>P\textsubscript{1μ}</th>
<th>REV, cm\textsuperscript{3}</th>
<th>V (full-diameter core), cm\textsuperscript{3}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core depth, m</td>
<td>1693.1</td>
<td>204.3</td>
<td>205.5</td>
<td>213</td>
</tr>
<tr>
<td>REV, cm\textsuperscript{3}</td>
<td>221.81±5</td>
<td>296.01±5</td>
<td>316.61±5</td>
<td>288.71±5</td>
</tr>
<tr>
<td>V (full-diameter core), cm\textsuperscript{3}</td>
<td>331.40</td>
<td></td>
<td>509.47</td>
<td></td>
</tr>
</tbody>
</table>

After definition of representative elementary volumes, it is concluded that for future investigations it is necessary to use additional core samples 7.5 cm long by 3 cm in diameter and core samples 4.5 cm long by 3 cm in diameter to increase the set of statistical data.

Conclusion

The concept of the representative elementary volume is considered in the article using the main theses of the theory of structured continuum. Representative elementary volumes of Devonian and Permian sandstones have been calculated concerning their open porosity. Some practical approaches and methods for definition of RVE including photogrammetry and X-ray computed tomography have been investigated.

Open porosity ratios of investigated sandstones were defined while using the buoyancy method and the helium porosimetry method. The regularity between maximum deviation of the open porosity ratio from average value and core volume has been shown for every core sample. It holds that for all full-diameter sandstones there is an inverse relationship between maximum deviation of open porosity ratio varying from 0.001\% to 6.201\% and core volume.

Representative elementary volumes of investigated core samples have been defined by the approximation of calculated maximum deviations of open porosity ratios. The representative elementary volume of the Devonian sandstone is 221.81±5 cm\textsuperscript{3} while the average RVE of all Permian sandstones is about 300 cm\textsuperscript{3}.

Consequently, it is necessary to investigate representative core samples extracted from every studied coring period to calculate accurate values of open porosity of productive formations in petrophysical laboratories. In future investigations, we are to define representative elementary volumes of limestones recovered from bitumen horizons of the Republic of Tatarstan.
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Formation Model of Conodont Biofacies (Upper Devonian, Voronezh Anteclise)

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Abstract

Various criteria for selection of biofacies, and principles of paleoenvironmental models for construction of conodont habitat are considered. A model of formation of conodont biofacies, based on the distribution of conodont assemblages in the Frasnian (Upper Devonian) of the Voronezh Anteclise (Central regions of the Russian Platform), is proposed.

Keywords: conodont biofacies, Upper Devonian, Voronezh Anteclise

Introduction

Conodonts are a globally distributed group of marine Paleozoic and Triassic fossils. It was assumed for a long time that conodont assemblages are independent of facies, since the same species can be found in a wide variety of marine sedimentary rocks. In this regard, conodonts are widely used for the correlation of various facies deposits. Besides their widespread stratigraphic use, they are important for paleoenvironmental reconstruction. The analysis of paleoenvironments begins with the identification of conodont biofacies, which are associations of conodont elements of the same age in sedimentary rock, with the predominance of certain genera and species that suggest habitat and sedimentation conditions.

To explain the difference in the distribution of Devonian conodonts, various models were proposed (e.g., [1], [2], [3], [4], [5] etc.). It was assumed that the composition of conodont associations was affected by distance from the coast [1], basin depth [2], [6], a combination of these criteria [3], [4], salinity and the degree of water mobility [6]. To date, conodont biofacies have been established for different stratigraphic intervals [7].

For the upper Devonian, conodont biofacies were first identified by E.C. Druce [8]. In Northern Australia, he identified three groups of conodonts (Belodella biofacies, Icriodus biofacies, and Palmatolepis biofacies), named for the dominant genera. On the East European platform, the first studies of the distribution patterns of conodonts in Upper Devonian sediments were made by V.G. Khalymbadzha [9]. Based on taxonomic differences in the associations, he identified three ecological groups: shallow-coastal, open sea and reef. On the Voronezh Anteclise, conodont biofacies for the Devonian were first established by V.A. Aristov [10]. He identified 5 biofacies according to their dominant genera, but noted that analysis of the conodont distribution at the generic level is insufficient; separation into biofacies associations can be done using different species of the same genus. Indeed, with research in different regions and at different stratigraphic levels, a similar pattern appears: the separation into biofacies becomes more and more refined, apparently more accurately reflecting paleoecological conditions.
Methodology

Biofacies are conodont associations in sediment, and in order to restore paleoenvironments, it is necessary to imagine how these associations were formed, and determine the role of the environmental conditions in the lives of the organisms, as well as the role of sedimentation features. The first biofacial formation model was proposed by E.C. Druce [1]. In this model, the change in conodont habitat occurred laterally; the main point was the distance from the coast. However, this model did not explain the presence of some taxa in almost all biofacies.

Seddon & Sweet [2] proposed a stratification ecological model similar to the distribution of modern Chaetognatha living at different depths. Only near-surface forms were buried in shallow sediments; in deeper sediments, the entire association of animals living at different levels of the water column was preserved. Later Druce [3] supplemented Seddon & Sweet’s stratification model with the thesis that the greatest number of specimens and species of conodonts were restricted to the bottom region at corresponding depths, which explained the numerical superiority of some taxa over others in specific biofacies. However, this implies the presence of near-surface cosmopolitan species in shallow water. In practice, endemic species are usually found in shallow sediments, which has conventionally complicated the correlation of shallow sediments with the standard zonal scale [11].

A separate nearshore conodont habitat was proposed in a model by Klapper & Barrick [4]. This model shows a change in the near-surface ecological groups of conodonts with invariable bottom ones, which is strange, since the benthic environment in the euphotic zone is more contrasting and diverse than the pelagic one, contributing to the creation of many ecological niches. In the model proposed by E.M. Kirilishina & L.I. Kononova [4] the change of bottom associations was considered in detail, but an independent coastal habitat was not identified.

Results and Discussion

In this research, based on material from the upper Devonian of the Voronezh Anteclise, we propose an improved model for the formation of conodont biofacies (Fig. 1), taking into consideration the advantages and disadvantages of previous models.

![Fig. 1. The model for the formation of conodont biofacies in sediment: B1, B2, B3, B4, B5, B6, B7 – conodont biofacies in sediment; M1 – coastal-shallow-water habitat of conodonts; MII – near-surface habitat of conodonts; MIIIa-e – habitat levels of conodonts in the pelagic area](image-url)
According to our model, there were three conodont habitats: $M_I$ – coastal extremely shallow (predominance of representatives of the genus *Icriodus*); $M_{II}$ – near-surface epipelagic, represented by cosmopolitan species of the genera *Icriodus* and *Polygnathus*; $M_{III}$ – is a pelagic region that also includes bottom habitats, containing a number of levels, varying in depth and with the predominance of representatives of certain genera. Closer to the bottom, at each depth level, the greatest number of individuals were found.

In sedimentary rocks, this model is reflected by the presence of seven conodont biofacies (from shore to sea): 1) **Biofacies $B_1$** corresponds to the coastal extremely shallow $M_I$ region, with representatives of the genus *Icriodus*, including endemic ones, predominating; *Polygnathus* may be also present, and, marginally, *Pelekysgnathus*; 2) **Biofacies $B_2$**, besides endemic species characteristic of the biofacies $B_1$, contains representatives of cosmopolitan species, predominantly of the genera *Icriodus* and *Polygnathus*, i.e. it is formed from representatives of the habitats $M_I$ and $M_{II}$; 3) **Biofacies $B_3$** represented by a predominance of smooth or poorly ornamented representatives of the genus *Polygnathus*; 4) **Biofacies $B_4$** with a predominance of well ornamented representatives of *Polygnathus*; 5) **Biofacies $B_5$** with a predominance of representatives of the genus *Mesotaxis*; 6) **Biofacies $B_6$** with a predominance of representatives of the genus *Ancyrodella*; 7) **Biofacies $B_7$** with a predominance of representatives of the genus *Palmatolepis*. Biofacies $B_3$, $B_4$, $B_5$, $B_6$, $B_7$ include conodonts from several depth levels of pelagic habitats, but the prevailing taxa will be those that existed near the bottom at a given depth, and they will determine the type of biofacies. Thus, representatives of shallow-water biofacies (except biofacies $B_1$) can be found in small numbers in deeper biofacies, but the remains of deep-water taxa are not found in shallow-water biofacies. During transgressions, deep-water forms can penetrate where there was previously shallow water, but this leads to a change in the type of biofacies. It should also be noted that all levels considered are in the euphotic zone within the shelf; it is impossible to indicate the exact depth of habitation of different groups; we can only operate with the relative concepts of deeper/shallower.

**Conclusions**

Consideration of the principles of construction of palaeoecological habitat models for conodonts allowed us to propose a scheme that took into account the positive elements of the models of previous researchers, and summarizes the data obtained during the study of the Frasnian shallow sections of the Voronezh Anteclise.

**REFERENCES**


Nuclear Magnetic Resonance Spectroscopy Applied to the Complex Study of Carbonate Core Samples

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Abstract

Core analysis is the basis for any study related to hydrocarbon exploration. Today, many researchers note the importance of using the whole core in the studies in order to obtain the most complete picture of the reservoir properties. This paper describes the application of nuclear magnetic resonance (NMR) spectroscopy to the study of a whole core sample. The porosity determined by NMR spectroscopy was compared to the log data. NMR spectroscopy shows better results in carbonate reservoirs than natural radioactivity measurements. Therefore, NMR spectroscopy increases the information content of studies, and can be recommended for general use.

Keywords: nuclear magnetic resonance, carbonate core, natural radioactivity, whole core, well logging

Introduction

Core samples play an important role in hydrocarbon exploration. The effects of host rocks and borehole conditions are significantly reduced when the samples are subjected to laboratory petrophysical studies. The reservoir properties determined in the laboratory are more realistic than the log data. However, in most cases, the filtration-volumetric characteristics are determined using the standard core plugs (cylindrical shape, 30 mm in diameter), which does not guarantee reliable information on the properties of reservoirs.

One of the main tasks in core analysis is comparison of the laboratory results with the log data. Proper recovery and transportation of the core samples and accurate correlation with the log data result in a reliable geological model of the reservoir [1]. Short sampling intervals may reduce the accuracy of depth control. As a result, petrophysical properties may not match. Still, correlation of the core plugs is a complicated procedure. The use of whole core samples simplifies the process. Gamma-ray spectroscopy is usually used for correlation in this case.

However, natural radioactivity in carbonate rocks is extremely low. Therefore, it is difficult to separate reservoir layers from dense rocks, since both of them can be characterized by the same lithotype. This paper proposes an alternative approach to the correlation of core data and log data.

Modern technologies allow accurate estimation of the filtration-volumetric characteristics of whole core samples. As a rule, this applies primarily to X-ray computed tomography [2] and flow permeability measurement [3]. However, they are mostly used for the positioning of core samples in standard core analysis, and are not binding. This paper provides an example of the application of NMR spectroscopy to porosity estimation.
Object of the Study

One of the wells located within the Akan oil field was chosen as the object of study. The oil field is located in the eastern part of the East European Plain. The deposits are of Bashkirian age (Carboniferous) and have a three-part structure (Fig. 1).

![Fig. 1. Location and geological structure of the studied object: (1) anhydrite; (2) marl; (3) clay; (4) limestone; (5) oil saturation; (6) location of the oil field](image)

The upper part of the succession (1152.5-1167 m) is composed of dark brown limestone with packstone structure, uniformly oil-saturated. The major producing horizon is located in the middle part of the Bashkir tier (1167-1184 m), from which the core samples were taken. It is composed of limestone with packstone-grainstone structure, nonuniformly oil-saturated, with numerous inclusions of light gray dense original rock, which is carved by subvertical fractures and cavities filled with oil or anhydrite. There are also occasional greenish-gray clay layers, and finally, greenish-gray clayed limestone with wackestone structure, also nonuniformly oil-saturated.

The lower part of the succession (1184-1196 m) is composed mainly of dense light gray limestone with numerous greenish-gray interlayers. There is almost no oil in this part of the section.

Methodology

There are different ways to determine porosity basing on the core data or log data. In laboratory core studies, there are several methods for determining petrophysical characteristics, and there are also several log curves that can be used for the same purpose.

Measurement of the natural radioactivity

The study of the natural radioactivity of the whole core sample was carried out using the “Krator” gamma-ray spectrometer produced by “EcogeosProm” (Tver, Russia). Before each
measurement, the spectrometer was calibrated using the control samples for the correct
determination of the natural radioactivity and density. The core sample was moving at a speed
of 25 mm per minute, the measurement step along the core axis was 100 mm. At each
measurement point, the radiation spectrum ranged from 40 to 2700 keV [4]. Uranium U,
thorium Th and potassium K isotopes were identified as a result of the spectrum analysis. In
addition, a total radioactivity curve was obtained. It indicates the total content of radioactive
isotopes in the core sample. This curve was used in further work.

**Measurement of the NMR porosity for the whole core sample**

As soon as the core sample was recovered from the well, it was subjected to NMR
spectroscopy. Many researchers remarked on the benefits of this approach [5], [6]. This method
is non-destructive and allows study of the whole core sample without any preliminary
preparations [7]. As a result, porosity, permeability and pore size distribution can be obtained
in a very short time. NMR measurements are especially important for NML equipment
calibration and proper analysis of the log data.

All measurements were carried out using the “NMR-Core” [8] installation developed at the
Kazan Federal University in conjunction with the specialists of “TNG-Group” LLC. This is
mobile equipment that can be used in field. The magnetic system is based on Halbach array.

The proton resonance frequency is 8.2 MHz. The installation measures the filtration-
volumetric parameters of a whole core sample with a step of 10 mm along the core axis.

During the work, 27 m of core was studied. Measurements were carried out using the Carr-
Purcell-Meiboom-Gill pulse sequence [9]. The following measurement settings were selected:
pulse width – 2 s, pulse spacing – 0.3 ms, repetition time between pulse groups – 3 s, the
quantity of pulses – 4. The transverse relaxation curve was then analysed [10] and the total and
effective porosities were calculated over the entire studied interval [11].

**Core plug porosity assessment**

Porosity can be measured in many ways: volumetric, gravimetric, and gas expansion
methods can be used for this purpose. However, the most common and accurate methods are
gravimetric methods [12].

It is well known that; the core sample has to be properly prepared for porosity measurements.

After the extraction, the samples are placed in a drying cabinet. When they are completely
dry, they are weighed and then saturated with the preferred fluid (water, kerosene) in a vacuum
(dense samples are saturated under certain pressure). The saturated samples are weighed again
in the fluid and in the air [12].

Standard laboratory studies were carried out using the same core sample that was used in the
NMR study. More than 100 cylindrical core plugs with a diameter of 30 mm were cut out. The
porosity was determined by the volumetric-gravimetric method.

**Calculation of porosity from logging data**

Laboratory measurements are quite accurate, but not always representative due to the limited
number of samples. In our case, additional information can be extracted from the highly detailed
log data.

The following logs were used for the analysis: gamma-ray log, density log and neutron
gamma log. All of them are of particular interest in the context of this work.

The approach described by William K. Mitchell and Richard J. Nelson [13] was used for the
porosity determination. It allows development of the sample’s model taking into account
lithological composition, pore volume and fluid saturation. The calculations were carried out
using the PowerLog StatMin module. Radioactive logs (GR, RHOB, W) were used as input
data.
Results and discussion

The total content of radioactive elements was obtained by analysing the natural radioactivity curve. This curve is usually used for core/log data correlation. This approach is particularly useful when there is a clear succession of layers with different clay content.

Figure 2 (on the left) shows the comparison of two natural radioactivity curves obtained from the core data and the log data. As was mentioned above, the studied section mainly consists of carbonate rocks. Clay starts to appear in significant quantity only at 1184 m. Carbonate rocks contain very few radioactive elements due to the nature of their sedimentation process. Moreover, the curve is rather smooth (there are almost no changes in the values along the profile). The same patterns can be observed on the curve GR(CORE). The figure shows clear divergence of curves especially in the lower part of the section (at ~1184 m). Up to this point it is impossible to say for sure whether there is a depth shift and how severe it is.

![Fig. 2. Initial log data and the results of the whole core study](image)

Figure 2 (on the right) shows NGR and RHOB curves obtained during well logging. The thin brown line represents the total porosity curve MPHI obtained using the “NMR-Core” installation. The MPHI curve is in good agreement with the logging curves up to a depth of 1174 m. Below, there is a discrepancy between the curves due to the depth shift. It should be noted that this could not be seen if only natural radioactivity curves are used.

As a result, the depth shift was eliminated using both the GR curve and the MPHI curve containing information about dense and porous interlayers.

The next step was the interpretation of the logging results followed by the laboratory studies in order to determine the porosity of the core plugs.

Figure 3 (on the left) shows the radioactive logs and the natural radioactivity curve. To the right of the depth scale, there is a model based on the log data [13]. As can be seen, the section
is mainly represented by limestone (VOLLs) with small amount of clay in the porous part and large amount of clay (VOLCL) in the lower part. The oil content in the productive part of the section (BVHSM) varies from 70 to 90%. The right half of Figure 3 shows the porosity determined by different methods. The black curve represents the porosity derived from log data [13]. The brown curve displays the total porosity MPHI (CORE) determined by NMR for the whole core sample. These curves are supplemented by the results of laboratory studies conducted on cylindrical core samples – POROSITY (CORE).

![Fig. 3. Core analysis results compared to the well logs](image)

The NMR porosity values coincide with both the log data and the laboratory data. Thus, NMR spectroscopy can be successfully used for a rapid assessment of reservoir properties.

**Conclusion**

In the course of this work, the carbonate core sample was studied using NMR spectroscopy, natural radioactivity method, well logging and laboratory measurements. The NMR porosity was successfully used for matching the core/log data. The effectiveness of this approach applied to the carbonate section is shown in comparison with the traditional natural radioactivity method. The porosity determined for the whole core is the same as the porosity obtained from the log data and the laboratory data.

Therefore, NMR spectroscopy increases the information content of such studies and can therefore be recommended for general use.

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Paleomagnetic Data on Samples from Babii Kamen (Kuznetsk Basin)

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Abstract

This paper presents the results of petromagnetic and paleomagnetic studies of Permian-Triassic rocks of the Babii Kamen section (Kemerovo Region, Russia, section base 54°23,079’N, 087°32,105’E). Over 160 samples taken during 2016 and 2018 field seasons were studied. The succession is consisting of sandstone, siltstone, and claystone and contains a vast amount of tuffaceous material. All the samples were subjected to thermal and alternating field demagnetization. Then, petromagnetic characteristics and magnetic susceptibility anisotropy were measured. The petromagnetic data showed changes in the composition of the volcanic component of the sediments at a depth of 50 meters above the base of the studied section. A preliminary magnetostratigraphic diagram is composed from the obtained paleomagnetic data.

Keywords: Magnetic properties, Paleomagnetism, Polarity, Permian-Triassic boundary, Babii Kamen section

Introduction

The largest Permian-Triassic extinction of the Earth’s marine and continental biota in the Earth’s geological history is one of the widely known and discussed problem in the geological and in the entire scientific community. Despite the enormous information accumulated on this subject, many issues critical to the understanding of the problem remain unresolved. To date, uncounted number of hypotheses and models describing the causes of extinction have been suggested, but none of them are universally accepted. In recent years, most experts are inclined to believe that Siberian volcanism and the products of its eruption, as well as the impact of the traps on the erupted rocks (hydrocarbons and evaporites) are the main reasons for the sharp increase in carbon dioxide, sulphides and other sublimates in the Earth’s atmosphere and in oceans. The trap eruption must have preceded to be a trigger of the global extinction of the biota global-wide. Therefore, the problem of the onset of Siberian trap eruption and the precise calibration of all phases of the development of trap volcanism is the most critical issue.

Determination of the age of each layer in the studied succession) can be carried out in many ways. Cyclic changes of the magnetic field of the Earth provide the opportunity to trace these changes through the geologic time. Petromagnetic and paleomagnetic methods of the calibration of sedimentary successions, besides geochronology and biostratigraphy, may improve and/or clarify the local, regional and global correlation of the geological events, such as Siberian traps explosion.

This paper presents petromagnetic and paleomagnetic data obtained from the large collections of the samples collected in Babii Kamen section during 2016-2018, which are partially overlap.
Methodology

Paleomagnetic studies were carried out using the Cryogenic (SQUID) magnetometer 2G Enterprises (USA) located in a nonmagnetic room in the Laboratory of the Main Geomagnetic Field and Petromagnetism of the Institute of Physics of the Earth, RAS, Moscow. The procedure included measurements of natural remanent magnetization (NRM), thermal demagnetization and alternating field cleaning. At low temperatures, the demagnetization step was 50 °C, then 40 °C. Above 555 °C, the step was 15 °C and 10 °C. Alternating field cleaning was carried out up to 90 mT. The data were processed using the specialized software package – Enkin.

Anisotropy was measured for the 2018 sample collection using a Multi-function Kappabridge MFKA1-FA (AGICO, Czech Republic). For data processing and visualization, the Remasoft 30 software package (same producing company) was used.

Results and Discussion

The magnetic cleaning results indicate that the paleomagnetic record is quite noisy. The principal component analysis is almost impossible for a large number of samples. 95% of NRM is removed during the heating to 520-590 °C. This fact indicates that magnetite and titanomagnetite are the main magnetization carriers, and the magnetization itself is most likely of an orientational nature. The Zijderveld plot, the stereogram and the demagnetization curves obtained for sample 3bk21 are shown in Figure 1.

![Zijderveld plot, stereogram, and demagnetization curves](image)

**Fig. 1.** The Zijderveld plot, the stereogram and the demagnetization curves obtained during the thermal demagnetization

Despite this, the high-temperature component (with normal and reverse polarity) was identified in 95 samples. The average paleomagnetic directions were calculated for the high-temperature component with normal (HT-N) and reverse (HT-R) polarity, as well as the average
for all samples (HT-all). The results are shown in Table 1. The reversals test was ineffective. This is probably due to the thickness (more than 200 m) of the sedimentary sequence, i.e., the large time interval during which the rocks were forming. The presence of samples with both normal and reverse polarity indicates the primary nature of the isolated components (Fig. 2).

Table 1. The results of the paleomagnetic study

<table>
<thead>
<tr>
<th>Number of samples</th>
<th>Geographic Coordinate System</th>
<th>Stratigraphic Coordinate System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D (°)</td>
<td>I (°)</td>
</tr>
<tr>
<td>HT-N</td>
<td>74</td>
<td>233</td>
</tr>
<tr>
<td>HT-R</td>
<td>21</td>
<td>25.6</td>
</tr>
<tr>
<td>HT-all</td>
<td>95</td>
<td>219.6</td>
</tr>
</tbody>
</table>

For the duplicate samples (from the 2018 collection mostly), a detailed (20 steps) alternating field cleaning (up to 90 mT) was performed. The polarity signs obtained with alternating field cleaning coincide with those obtained during the thermal demagnetization in 95% of cases. However, there are some discrepancies in the paleomagnetic directions.

The paleomagnetic directions obtained during the study were utilized to compile the preliminary magnetostratigraphic diagram. A polarity zone contains two or more samples with the same polarity. Thus, the lower 18 meters of the studied section is the normal polarity zone. In the interval of 19-37 m, there is the zone with mixed polarity. It is followed by the normal polarity zone again (stretching to the benchmark of 89 m). There is also a strong shift in the scalar magnetic parameters inside this zone (Fig. 2). Several studies assume that this shift occurs at the P-T boundary [1], [3]. If so, the normal polarity zone identified from 37 to 89 m in Babii Kamen’ section stretching from the Upper Permian to the Lower Triassic. This zone was also spotted earlier in many publication [2 and references herewith]. Moving up the section, at elevations of 90–95 m, the polarity sign changes frequently, and the small reverse polarity zone appears which is then replaced by the continuous normal polarity zone. At the top of the section (165-195 m), there is the reverse polarity zone (Fig. 2).

According to the petromagnetic and paleomagnetic data, the main magnetization carriers in the studied samples are magnetite and titanomagnetite, which justifies the use of these samples in paleomagnetic studies. The results of the previous magnetic and mineralogical studies of this section [4] are consistent with the results obtained from the samples taken in 2018. In the lower part of the studied section (up to about 50 meters), the average magnetic susceptibility is $0.32 \cdot 10^{-3}$ SI, NRM $6.6 \cdot 10^{-3}$ A/m, at and above the 50th meter in the studied section $4.27 \cdot 10^{-3}$ SI и $81.2 \cdot 10^{-3}$ A/m respectively (Fig. 2). This is most likely due to the introduction of a large amount of the magnetic material into the basin that is most likely associated with the Siberian trap’s volcanism.

The magnetic susceptibility anisotropy does not exceed 6-7% in all cases, except for a few samples. The minimum value axes are directed sub vertically, the maximum value axes are located in the horizontal plane and are rather closely grouped in the southeast. The latter indicates that the paleocurrent was rather moderate and directed northwest to southeast.
Fig. 2. Variations of the petromagnetic and paleomagnetic parameters in Babii Kamen section. Summary of the two sample collections (2016 and 2018). Polarity: black – normal, white – reversed, grey – variable polarity, cross – no paleomagnetic data; NRM – natural remanent magnetization; D – declination; I – inclination.
Conclusion

The study showed that petromagnetic and paleomagnetic data can be used for dividing the section into the units. According to our studies, we propose the tentative position of the Permian-Triassic boundary in Babii Kamen section at 50 meters from the bottom of studied interval, where the main shift in petromagnetic parameters is recognized. Changes in polarity also assign the layer to the succession (Permian or Triassic). Further data processing and calculation of the paleomagnetic poles combined with other methods (geochronologic and biostratigraphic) will provide a more precise boundary position between the two systems. In order to obtain more accurate result, thermal demagnetization and alternating field cleaning data should be compared, and the calculated poles should be cross checked with the reported data for the neighbouring territories.

Acknowledgements

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REFERENCES

Carbonate Nodules with Aluminum and Iron in the Karst Cavern of the Upper Devonian-Lower Carbonic Limestones (Middle Urals, Russia)

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Abstract

The article describes carbonate nodule formations which contain Al, Fe, and are associated with the Upper Devonian-Lower Carbonic limestones (D³-C¹) of the Middle Urals. The studied formations are distinctive due to their red colour and concentric fissility. The mineral composition of the formations is the carbonate (mainly calcite), hematite, chlorite, kaolinite, hydromica. The host sediments have a similar composition and represent a filling of the karst cavern in the block of limestone. According to some indications (nodule enveloping by overlapping layers, identical mineral composition), it can be deemed possible that nodules were formed concurrently with the host rocks, and thin fissility testifies to the conditions of a calm aquatic environment in the limestone karst cavern. It should also be noted that sediments bear traces of hydrothermal changes.

Introduction

In the limestones of the Upper Devonian and Lower Carboniferous, the Khvoshchovsky-2 cast mine was uncovered. It is located in the territory of the Safyanovsky mine of 10 km north-east of the city of Rezh (Fig. 1). It is a karst cavern with red and gray-colored clay-like deposits which contain nodules of red colour and range in size from millimetres to several tens of centimetres in size. They are, mainly, flattened-spherical in shape.

Fig. 1. Overview map of the sampling site with nodule formations (marked as red rectangle)
The karst cavern is located in the limestones of gray and dark gray colour, which are micro-layered and unevenly fine-grained. Fissility is emphasized by numerous fragments of thin shells of brachiopods (?) 1 to 3 mm long. The rock contains algae, which is unevenly scattered, elongated along the fissility of the pelloids, or spherical in shape. The rock is fractured; cracks are formed by coarse-grained calcite. Thin stilolite seams formed by a dark organic matter can also be seen (described by G. A. Mizens).

The karst cavity is filled with carbonate-clay thin-layered deposits, where red and light gray layers are alternating. The mineral composition of the deposits is represented by calcite. There is an admixture of chlorite, mica material and kaolinite, and hematite in the red varieties. The Al₂O₃ content in the host rocks reaches 22% by weight (chemical analysis data from the South Ural Center of Collective Use Research for Mineral Resources, Institute of Mineralogy of the Ural Branch of the Russian Academy of Sciences (RAS).

Nodules of the karst cavern have a predominantly flattened-spherical appearance, and a shell-like nature (Fig. 2, a, b, c); the thinner concentric fissility is less common. There are no macrofossils. The pores are either empty or filled with thin crystalline and fine crystalline calcite. Nodules occur like a layering of sediments: this indicates that their growth occurred during the formation of sedimentary layers.

Research Methods

The mineral composition of the nodules and host rocks was studied by X-ray diffraction analysis (diffractometer, XRD-7000 Shimadzu; performed by operator, O. L. Galakhova) in the Laboratory of physical and chemical research methods of the Institute of Geology and Geochemistry of the Ural Branch of the Russian Academy of Sciences (RAS).

Detailed studies of the crushed and cut surfaces of various nodule zones were carried out via scanning electron microscopy (JEOL JSM-6390LV; carbon spraying), the elemental composition of the samples was studied by energy dispersive spectrometry (IncaEnergy 450) in the Laboratory of physical and chemical research methods of the Ural Institute of Geology and Geochemistry Branch of the RAS, performed by operator S.P. Glavatsky.

Research Results

According to X-ray diffraction analysis, nodules from the karst cavern contain mainly calcite (63%) with the following lattice parameters: a = 4.972 Å; c = 16.978 Å, kaolinite (up to 10%), hematite (up to 6%) and impurities of mica material, quartz and chlorite.

The study of nodule samples on fresh cuts performed by scanning electron microscopy showed that it consisted of densely arranged grains of calcium carbonate. The carbonate grains are coated with a thin film layer. Accessory minerals, in particular chrome spinel, micaceous formations, kaolinite and chlorite, are rarely found. Silica minerals are represented by quartz crystals (Fig. 2, c) and thin non-crystalline formations similar to a bacterial film replaced by silica (Fig. 2, d). In addition, spherical microfossil with a specific morphology (Fig. 2, e) formed by apatite.
Fig. 2. Nodule formations with Al and Fe of the Upper Devonian – Lower Carboniferous limestones of the Middle Urals (mine Khvoshchovsky-2): a) nodules of various sizes and morphologies from the karst cavern of limestone; b) a photo of nodule with concentric fissility; c) an electron microscopic image of the crush cut surface of a nodule with a quartz crystal (spectrum 90); d) a bacterial film substituted by silicon dioxide (spectrum 12); e) a microfossil represented by apatite (?) (spectrum 156)

The Discussion of the Results

Film formations (Fig. 2 d) in the predominantly carbonate substrate of nodules are of particular interest. These films are formed by silica, and are interpreted as mineralized bacterial biofilms. It was established that the biopolymer substance appeared during the life of microbial
organisms and could be replaced by silicon dioxide compounds [1, 2, 3]. The issue of how Al and Fe accumulation in the studied nodules occurred is not yet completely clear. Clay fissility containing nodules are gray and red-brown. The reddish layers contain more iron, which is mainly found in hematite. Perhaps, in this case, the seasonal fluctuation of sedimentation in the paleobasin played a certain role. Al transfer is possible in the form of finely dispersed colloidal particles (0.1 to 1-2 μm), which are one of the main patterns of aluminium migration in solutions [4, 5], followed by deposition in clay fissility and nodules.

The deposits of the karst cavern, as well as the host limestones, bear traces of hydrothermal effects, as evidenced by numerous secant calcite lodes. Hydrothermal study is confirmed by the presence of mica minerals, kaolinite and chlorite, as well as hematite in the deposits of the karst caverns.

Conclusions

The studied nodules are syngenetic to the host deposits of the karst cavern. Although the nodules have the same mineral composition as the host clay rocks, they are indicated by isolation and concentric fissility (Fig. 2 a, b), and are rarely seen in the central part. The presence of mineralized biofilms in the studied samples (Fig. 2 d) may indicate bacterial activity during the building of nodule formations. The discovery of microfossil of probably apatite composition (Fig. 2 e) buried in a nodule substrate indicates the presence of eukaryotic organisms in the ecosystem, although such an asset is very rare.

The thin fissility of the deposits in the karst cavern which contain nodules indicates a calm aquatic environment and the seasonal deposition of sediments. The medium was probably saturated with calcium and carbon dioxide and had an alkaline pH reaction. Al and Fe compounds could get into the sediments when transported by sediments in the form of colloidal particles. And the formation of aluminous and glandular minerals is probably affected by hydrothermal fluid. The hydrothermal effect is confirmed by newly formed calcite lodes, where calcite has a reddish-brown tint due to oxidized iron.

Acknowledgments

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REFERENCES

Cephalopods of the Early Permian Shakh-Tau reef

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Abstract

This paper presents the first results of the study of the cephalopod collection from the Early Permian Shakh-Tau Reef. This Late Asselian-Early Sakmarian ammonoid assemblage contains nine species of nine genera, some of which are identified in open nomenclature. In the Early Permian (Asselian-Sakmarian and Late Artinskian) assemblages of non-ammonoid cephalopods, about 30 species of coiled nautilids, four species of straight nautiloids (Orthocerida and Pseudorthocerida), and two species of Bactritida have been identified. In addition, two species belonging to the order Oncocerida were found in the Asselian-Sakmarian assemblage. The Asselian-Sakmarian reef community of non-ammonoid cephalopods differs significantly from the Sakmarian communities known from the basinal sediments of the South Urals, both taxonomically and in prevailing morphotypes. The Late Artinskian post-reef assemblage is closer in all respects to the Artinskian South Uralian assemblages, but also has its own characteristics.

Keywords: Ammonoids, bactritids, nautiloids, oncocerids, Early Permian, Urals, Shakh-Tau reef

Introduction

The Early Permian Shakh-Tau reef, one of the four Sterlitamak reef mounds (“shikhans”), has now been almost completely excavated by a limestone quarry and has ceased to exist. The history of the study, geological structure, and components of the bioherm facies have been the subject of a number of works, and were studied in particular detail by Korolyuk [1]. During the quarrying of the limestone, layers containing the richest invertebrate fauna, including cephalopods, were opened. The fossils were sampled in 2015-2019 by a team from the laboratory of molluscs of the Paleontological Institute (Russian Academy of Sciences), which included A.V. Mazaev, M.S. Boiko, and in the last year, A.Yu. Shchedukhin. Thanks to the enthusiasm and efforts of A.V. Mazaev, a unique collection of early Permian cephalopods, including the Asselian-Sakmarian and Late Artinskian assemblages of ammonoids, straight and coiled nautiloids and bactritoids was assembled in the laboratory.

Results and Discussion

In the collection studied, the Late Asselian-Early Sakmarian ammonoid assemblage includes nine species of nine genera: Neopronorites tenuis (Karpinsky), Sakmarites postcarbonarius (Karpinsky), Medlicottia subdorbignyi Gerassimov (Fig. 1, H), Agathiceras uralicum (Karpinsky), Somoholites shikhanensis Ruzhencev (Fig. 1, G), Paragastrio ceras aff. sterlitamakense Gerassimov, Uraloceras aff. limatulum Ruzhencev, Properrinites sp., and Propopanoceras sp. Previously, seven species of seven genera were recorded in Shakh-Tau [2].

In addition to the representative of the family Perrinitidae Miller and Furnish, 1940 [3], which was first discovered in the Urals, it was possible to establish the presence of Medlicottia...
in the Asselian-Sakmarian sediments, based on well-preserved material. Thus, the validity of *Medlicottia subdorbignyi*, a species established by Gerassimov [2] is confirmed. This means that the genus *Medlicottia* appeared a whole stage earlier than had previously been thought [4], [5], [6], [7]. *Uraloceras* is found in this locality for the first time.

The newly obtained and refined data made it possible to compare this assemblage with the Early Sakmarian assemblage from Yukon, which also contains a primitive *Perrinitidae* and ancient *Medlicottia* [8]. The Canadian assemblages are less taxonomically diverse, but 80% of their genera (five of seven) are the same as in Shakh-Tau. These are the genera *Properrinites (Subperrinites)*, *Medlicottia*, *Prothalassoceras*, *Uraloceras*, and *Somoholites*. The Pamir Asselian-Sakmarian ammonoid assemblage described by Ruzhencev [9] and Bogoslovskaya [10] is much richer than that of the Urals, out of 16 genera, four (25%) are shared: *Agathiceras*, *Prothalassoceras*, *Somoholites*, and *Properrinites*. In addition, the Pamir assemblage contains Prolecanitida: *Boesites*, *Metapronorites*, *Vanartinskaia*; *Goniatiitina*: *Glaphyrites*, *Eoasianites*, *Svetlanoceras*; *Adrianitina*: *Emilites* and *Cyclolobina*: *Almites*, *Cardiella*, *Tabantalites*, *Prostacheoceras*, and *Martoceras*.

The Late Artinskian ammonoid assemblage is studied by Boiko; it includes about 20 species of 15 genera and is a good source of data for a comparative analysis of the reef and basinal communities of the Early Permian ammonoids of the Urals. A paper on the results of this study is being prepared for publication.

The richest occurrence of nautiloids from the Asselian-Artinskian beds of Shakh-Tau is of particular interest. Even though many researchers pointed to the findings of non-ammonoid cephalopods on the shikhans, to date they have not been systematically studied. In recent years, based on material collected by A.V. Mazaev and M.S. Boiko, this unique nautiloid assemblage was preliminarily characterized by I.S. Barskov, who established in its representatives of the orders Pseudorthocerida, Orthocerida, Bactritida, and Nautilida [11]. In that collection, he found four specimens of curved shells, which, according to external morphology, corresponded to representatives of the order Discosorida (known from the Devonian) or Oncocerida [12].

Further study and the finding of another specimen with a preserved narrow marginal siphuncle confirmed the presence of Oncocerida (Fig. 1, A), which according to the most recent data became extinct by the Early Carboniferous. Altogether, around 30 nautilid species have been recorded from Shakh-Tau. The Asselian-Sakmarian coiled Nautilida include representatives of the following genera: *Endolobus*, *Stenopoceras*, *Rhiphaeoceras*, *Pararhiphaeoceras* (*P. aktastense* (Fig. 1, B), *P. sp. nov.*), *Tennochromeus*, *Domatoceras*, *Lirocera*, *Kokinckioceras*, *Megaglossocera*, *Permonautilus*. The Artinskian beds include species of the genera *Parastenopoceras*, *Sholakoceras*, *Condraoceras*, *Neothrincoceras*, *Metacoceras* (*M. subquadratum* (Fig. 1, C)), *Neodomatoceras*, *Pseudotemnocheilus*, *Lirocera*, *Hemilirocera*, *Gzhelecera*, *Lophocerax*, and also *Dentoceras* (*D. latum* (Fig. 1, D)) with a straight shell lacking a phragmocone.

In addition, straight Artinskian cephalopods are represented by Pseudorthocerida (species of *Uralorthoceras* (*U. tzwetaevae* (Fig. 1, E, F)), *Shikhanocera*, *Dolorthocera*) and Bactritida – Hemibactritida and Parabactritida.

Some of these taxa are species described by Shimansky [13], [14], other species and three genera are new.

No such taxonomically rich nautiloid assemblage is known from any other Permian site in the world. Usually one location contains no more than 2-5 genera and species. The richest assemblages of the Early Permian cephalopods (Sakmarian and Artinskian) were described by Shimansky [13], [14] from the basinal facies of the South Urals (several localities). Nautiloids from Shakh-Tau differ significantly in taxonomic and morphological composition from these assemblages, especially the Asselian-Sakmarian.
The Late Artinskian cephalopod assemblage, formed after the end of the life of the reef, is much more similar to that of the South Urals, although it also has its own characteristics. As noted by I.S. Barskov [11], the differences in the Asselian-Sakmarian reef assemblage mainly consist of the prevalence of coiled taxa over straight ones. In the basinal assemblages of the South Urals, the ratio is reversed.

According to the ratio of morphotypes, the Asselian-Sakmarian assemblage of nautiloids is comparable to the Roadian (Kazanian) community described from the quarries of the Kirov region and Mari-El, from sediments of reef origin [15]. In the Middle Permian reef community,
coiled forms also predominate, but, unlike the Shakh-Tau, they are represented by extremely smooth-cut forms, whereas in the Shakh-Tau ribbed shells make up about 50% of the coiled nautiloids.

Conclusions

The data obtained expand our understanding of the biological and morphological diversity of Early Permian cephalopods, their stratigraphic and geographical distribution, and also allow us to carry out paleobiogeographic and paleoecological studies. They open up new opportunities for a detailed study of the Permian reef buildups in the east of European Russia.

Acknowledgments

The authors express their deep gratitude to I.S. Barskov, the greatest specialist in cephalopods, who began this work. To our deep regret, illness and death prevented him from continuing his research. We, his students, consider it our duty to continue and complete what he began, as a tribute to the memory of this remarkable scientist.

REFERENCES

Detailed Stratigraphy of Multifacies Terrigenous Deposits from the Lower Carboniferous of Tatarstan (European Russia): Principles and Experience

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Abstract

Detailed stratigraphy of compound productive horizons of terrigenous origin within the Lower Carboniferous strata is introduced in this study. Ways of identifying and correlating the hydrocarbon-bearing layers in order to build adequate geological models are shown.

Keywords: Lower Carboniferous deposits, multifacies terrigenous deposits, stratigraphy

Introduction

Revising existing documentation of resource estimates and oil reservoir engineering has shown that the geological structure of oil fields usually remained understudied [1]. This is especially true for complex structures of oil fields, where the quality of geological models suffers from the lack of detailed stratigraphy for the drillings. In petroleum geology, a detailed correlation of the hydrocarbon-bearing part of the section is used for this; it allows to identify areas for exploration and development. According to expert estimates [1], [2], gross errors occur here especially often at the step of preparation of geological and hydrodynamic models of oil fields (not a single reservoir calculation or technological procedure documentation for development of the oil field can do without models). Most complex in terms of detailed stratigraphy are the productive strata, represented by various facies.

Methodology

The goal of detailed stratigraphy and indexation (identification) of reservoir layers in petroleum geology is the correlation of productive reservoir intervals, which is crucial for: a) subdividing the rock mass; b) selecting synchronized strata and indexing them; c) determining the extent of macro- or volumetric heterogeneity. In total, this allows the selection of areas for exploration and development.

To create an adequate geological model of a complex feature, a retrospective analysis with reconstruction of sedimentation conditions at different stages of its geological development is necessary, in connection with the establishment of certain traps, including of non-structural type [3].

Results

Possibilities for detailed correlation of well sections are considered here on the example of the Lower Carboniferous terrigenous rock mass (“TTNK”) of deposits in the east of Tatarstan, whose accumulation is usually attributed to the Visean stage (Kozhimian and Early Okskian
regional substages) (Table). Stratigraphic research performed in the 60s to 80s of the past century, focusing on the most variable Kozhimian part of TTNK by spore-pollen analysis (M.I. Moroko, TatNIPIneft), showed that among the hydrocarbon-bearing structures of the Republic, deposits of the Radaevian horizon and to a lesser extent of the Bobrikovian horizon are the most developed. In those structures, B-1 and B-2, respectively, sandstone and siltstone units were identified, which were later included by I.S. Gutman (1982) into a three-membered scheme [4].

It is conventionally assumed among specialists that the upper unit BB_{3}^{1} belongs to the Bobrikovian part of the TTNK section, and the lower units BB_{3}^{2} and BB_{3}^{1} belong to the Radaevian part. Normally one or two of these strata are present in different combinations in well sections, while combinations of all three occur less frequently. Each expansion field may differ in terms of frequent replacement of oil reservoirs by argillaceous varieties. Besides, areas of formation fusion are quite often found.

**Table.** Stratigraphic diagram of the productive Carboniferous deposits in the east of the East European Platform

<table>
<thead>
<tr>
<th>Stage</th>
<th>Visean</th>
<th>Superhorizon</th>
<th>Horizon</th>
<th>Lower Carboniferous terrigenous rock mass (“TTNK”)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tournaisian</td>
<td></td>
<td></td>
<td></td>
<td>Lower Carboniferous carbonate rock mass</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Okskian</td>
<td>Kozhimian</td>
<td>Bobrikovian</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shurinian</td>
<td>Radaevian</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Khanian</td>
<td>Kosvian (Elkhovian)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Kizelian</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cherepetian</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Upian</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Malevian</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Gumerovian</td>
</tr>
</tbody>
</table>

Conditions in the shallow subaquatic basin and the underwater currents in the coastal area were influenced by paleogeography and bottom topography of the Radaevian-Bobrikovian terrigenous reservoirs, which are characterized by a very complex shape. This concerns the so-called normal sections where sedimentation occurred continuously, with no visible interruptions.

During the exploration and development of oil fields in the Melekess Depression, South Tatar Arch, paleoriver drainage [4] was found, where a greatly increased thickness of the TTNK is genetically correlated with a respective reduction of the stratigraphic completeness of the Tournaisian carbonate rock mass. Kosvian-horizon argillites in the base of the Visean are also eroded in wells of the anomalous sections. Disputes about the nature of erosional downcutting’s have ceased when drillings in the Romashkinsky [4] and Arlansky [5] giant fields have proved their sleeve-like (according to Ivan Gubkin), or a shoe-string character and a channel nature, respectively. A similar morphology of erosional ravines is also present in smaller oil fields [4], [6].

Morphologically, river palaeovalleys look like narrow (0.1 to 3 km), wound arms up to 60 km or more in length. The total amplitude of erosional downcutting can reach 100 m and more [4], which proves recurrent onset of erosional activity [7] during the early Carboniferous period (Fig. 1, 2). The literature mentions cases of four to five times of revival of ancient river valleys in the middle Carboniferous of the northern border districts of the Donbass and three times of revival of ancient river valleys in the Volgograd Volga Region.
A well-known monograph [8] has documented overlapping channels filled with sandstones within sediments of the Graham Formation of the Upper Pennsylvanian Cisco Series in the Brazos Depression (Texas), where the total thickness of alluvium is about 150 m. The phenomenon of inheritance of Neogene-age river valleys is also typical for modern alluvial sediments.

![Fig. 1. Detailed correlation scheme with bed-by-bed resolution in the eroded area for three wells of the Suncheleyevsk oil field, Melekess Depression (based on R.Z. Mukhametshin, A.N. Akhmetov, 2013)](image)

It must be highlighted that a rather complex depositional environment also existed during the Tournaisian stage in territory of Tatarstan (despite the accumulation of mainly carbonatic sediments). It was G.I. Vasyasin [9] who first noted erosion-denudation phenomena in the Tournaisian deposits: reconstruction of the paleogeographic setting made it possible to segregate a group of continental and lagoon facies from marine series. Studies have shown that the rate of erosion-accumulation processes reached its maximum at the boundary between the Kosvian and Radaevian horizons [4]. At the same time, in all wells that anomalous sections, with no exception, the argillitic unit of the Kosvian horizon was found to be eroded.

Sandy rocks in sleeve-like erosional areas are characterized by a coarser grain composition of the fragmentary material, its loose laying. This leads to high reservoir properties of pay beds (up to the appearance of super reservoirs [4], [10]) and, accordingly, increased productivity of the oil wells. Additional alluvial sandy bodies found in erosional downcutting’s were proposed by us to be classified within formations of the BB\(_0\) group: BB\(_0^1\), BB\(_0^2\), etc. (top to bottom) [4] (see Fig. 2). All the his indicates the cyclic nature of erosion-accumulation processes in the Tournaisian-Kosvinian interval of the geological history.

Thus, the Lower Carboniferous terrigenous rock mass (TTNK) is a multifacial succession where the final Tulian sedimentation cycle is already represented by normal-marine, relatively deep-water sediments. A detailed correlation of Tulian-age sandstone and siltstone strata does then come easy.
Fig. 2. Detailed correlation chart of the hydrocarbon-bearing “TTNK” layers in production wells, one of the oil fields of the Melekess Depression: (gray fill – reservoir layers of the Tulian and Bobrikovian-Radaevian horizons, dark gray – coals and coaly shales) (based on R.Z. Mukhametshin, A.N. Akhmetov, 2013)

**Discussion**

To identify and synchronize of pay beds, we proposed to use such a fundamental factor as the persistence of the carbonate-terrigenous rock mass, located between the bottom of the Tournasian (marker C₁-1) and “Tulian limestone” marker horizon (Fig. 3).

The workflow for detailed stratigraphy of well sections of erosion-dominated successions can be outlined as follows:

A. Detailed correlation of sections of the hydrocarbon-bearing part of the Lower Carboniferous sediments. Several marker horizons can be distinguished in the latter – these are (from top to bottom) the TTNK tops (1); the “Tulian limestone” (2); the lower T-1 layer in the base of the Tulian horizon (3); the clays (argillites) of the Kosvian horizon (in “normal” sections) (4); C₁-5, the top of Tournasian (5); 6 and 7) interruptions of carbonate sedimentation represented by clay interlayers at the base of the upper (C₁-3) and lower (C₁-1) Tournasian, respectively.
Fig. 3. Stratigraphic correlation and indexing scheme of “TTNK” sections with erosive incisions

Legend: 1 – sandstones and sands, 2 – limestones, 3 – siltstones, 4 – argillites, 5 – coals and carbonaceous shales, 6 – clay content, 7 – boundary intervals corresponding to the profile position of the Bb0 area strata and the eroded Elkhovian(Kosvian)-Tournaisian deposits; reservoirs: T-1–T-3 – interval of the Tulian horizon, BB1 and BB0 are normal and erosive, respectively.

B. Hydrocarbon-bearing strata in erosive incisions of mainly Tournasian-Kosvian age must be correlated with respect to their position relative to lithounits and using coal seams and carbonaceous shales as marker horizons [4] (see Fig. 2, 3). The presence of the latter in the erosional part of the section, in combination with siltstones, obviously, reflects the Golovkinsky-Walter Law.

Conclusion

A detailed stratigraphic methodology for complex hydrocarbon-bearing sections is proposed on the example of the Lower Carboniferous oil and gas complex of Tatarstan, whose structure is aggravated by erosional downcutting’s. The nature of the reservoirs needs to be determined based on a retrospective analysis. In the next step, an algorithm for identifying reservoirs using their bed position relative to marker horizons and detailed correlation of well sections should be applied.

REFERENCES


Lithology and Stratigraphy of the Lower Kazanian within the Oil-Producing Territory of the Republic of Tatarstan: Hydrogeological Significance

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Abstract

Based on its stratigraphy and geomorphological position, the Lower Kazanian (Middle Permian) shallow-marine succession is considered as the most productive interval for fresh underground water. We construct a new map of water transmissivity for the Lower Kazanian aquifer on the base of stratigraphic reinterpretation of more than 2000 wells, as well as on the base of earlier identified filtration features of the rocks. This new map is based on both direct hydrogeological and calculated data. Parameters of underground water flow are obtained from this map. The values of these parameters correspond to experimental field definitions. The study will allow to plan and conduct exploration for fresh underground water more efficiently.

Keywords: Lower Kazanian, underground water, water transmissivity, subsurface water flow

Introduction

Environmental pollution processes occur over time in areas of intensive and long-lasting oil production. In this context, problems of providing drinking water to the oil fields and the local population become relevant. This is also true for the East-Kama region of the Republic of Tatarstan, where dozens of oil fields have been developed for more than 50 years. Among these oil fields, the Romashkino oil field and Novo-Elkhovskoye oil field are unique (Fig. 1). The East-Kama region is located within the Volga-Ural Antecline of the East European platform. Its area is about 20,000 km². The upper part of the sedimentary cover is composed of polygenic (marine and continental) sulfate-carbonate-tilligenous Permian and terrigenous Pliocene-Quaternary sediments. The thickness of the Permian succession reaches 400 meters. The maximum thickness of the Pliocene-Quaternary sands, silts and shales (up to 210 m) occurs in paleo-valleys and modern river valleys. The Lower Kazanian aquifer is the most productive stratigraphic interval for fresh underground water in this region. Knowledge of geofiltration and hydrogeochemical fields is necessary for exploration for underground drinking water and the rational drilling of water wells. These fields are usually shown on water transmissivity maps and on hydrogeochemical maps. The first map is usually based on data of aquifer tests in hydrogeological wells. Lithological and stratigraphic studies, coupled with filtration anisotropy data of the studied units, allow to create a map of water transmissivity using well sections without experimental filtration tests. The number of suitable wells exceeds the number of special hydrogeological wells by many times.
Fig. 1. Location of the East-Kama region in the Republic of Tatarstan: 1 – East-Kama region; 2 – large oil fields, abbreviated by Roman numbers: I – Bavlinskoye oil field, II – Novo-Elkhovskoye oil field, III – Romashkino oil field

Material and Methodology of Research

The Lower Kazanian aquifer is the main object of our study. It crops out in the lower slopes of many river valleys of the East-Kama region. Over ten fairly large underground water deposits have been explored in this territory. The distribution of water-bearing layers and aquicludes within the Lower Kazanian aquifer is determined by the stratigraphy of the Lower Kazanian substage. Currently, the Lower Kazanian succession (50-100 m) contains three units – Baitugan Beds, Kamyshla Beds and Krasnyi Yar Beds [1], [2]. These units were formed by three cycles of sedimentation. Each cycle (15-40 m thick) usually begins with sand or shale and ends with carbonate or argillaceous-carbonate rocks. Local stratigraphic schemes of the Lower Kazanian contain several marker intervals or “Members” (from bottom to top): “Tar (or bitumen, or Shugurovo) Sandstone”, “Lower Spirifer-Limestone”, “Lingula Shale Member”, “Middle Spirifer-Limestone”, “Upper Spirifer-Limestone”, etc. [3], [4].

Some marker intervals or “Members” are easily identifiable in outcrops and well cores. They play an important role in hydrogeological processes. So, the Lingula Shale Member occurs at the base of the Lower Kazanian in most parts of the East-Kama region. It is composed mainly of dark-gray calcareous shales with abundant accumulations of the inarticulate brachiopods Lingula orientalis Golovkinsky. The predominant thickness of the Lingula Shale Member is 10-15 m. It plays the role of a regional aquiclude and separates the zone of fresh underground water from the zone of brackish water in most parts of the oil-producing territory. The Middle Spirifer-Limestone Member and the Upper Spirifer-Limestone Member predominantly consist of carbonate rocks (in the western part of the region) or sandstones (in the eastern part) and represent the most water-bearing stratigraphic interval. The interval of the Lower Kazanian succession, which overlies the Lingula Shale Member, is defined as the Lower Kazanian aquifer (complex). The cyclicity of the Lower Kazanian succession is accompanied by facial difference.

Rocks of this stratigraphic level were formed in a wide range of sedimentary environments – from open marine shelf environment to continental lacustrine basins and alluvial channels. So, the change from marine to continental facies occurs both vertically (from bottom to top along the section) and laterally – from the southwestern to northeastern part of the East-Kama region [1], [2].

The authors have conducted a detailed study of the Lower Kazanian succession and the underground water from the Lower Kazanian aquifer. The data for this study come from the stratigraphic sections of 2,308 wells and 79 outcrops (Fig. 2), the results of experimental
filtration testing of 552 hydrogeological wells, the results of 122 laboratory determinations of the filtration capacity of the main rock types, and the results of 1217 chemical analyses of groundwater.

Fig. 2. Location of the studied outcrops and wells: 1 – outcrops, 2–6 – wells: 2, 3 – structural wells; 2 – uncored wells, 3 – wells with core sampling along the entire drilling; 4, 5 – exploration wells: 4 – geological wells, 5 – hydrogeological wells; 6 – water intake wells

Detailed reiterated interpretation of stratigraphic data for each outcrop and well allowed to obtain information on the absolute altitudes of the base and the top of the Lower Kazanian substage, its thickness, the thickness of the *Lingula* Shale Member, the facial features of this member, and the facial features of the overlying members. In addition, data on total and effective thickness of the Lower Kazanian aquifer and its water transmissivity are obtained.

Water conductivity is calculated by multiplication of the aquifer thickness and its filtration coefficient. Based on the practice of hydrogeological studies, only strata of sandstones and limestones with dolomites are considered as aquifers. The filtration coefficients of aquifers were taken from specially compiled tables, where 252 filtration coefficient values for each structural element of the East-Kama region are calculated, for sandstones and calcareous rocks separately, depending on their hypsometric, geomorphological and geological position. Patterns of regular filtration capacity changes, revealed for the Lower Kazanian aquifer (e.g., [5]) were used as a base for constructing these tables.

The water transmissivity map of the Lower Kazanian aquifer (Fig. 3) compiled from data of hydrogeological wells and all wells of other types should have maximum reliability. This map has been used in a next step for determining the main characteristics of the underground flow of the Lower Kazanian aquifer, which is widespread in the East-Kama region. Its recharge occurs mainly due to atmospheric precipitation infiltration and overflowing from overlying formations. The bulk of the discharge occurs in numerous spring sources and filtration into ancient (Pliocene) and modern river valleys.
The piezometric surface of the Lower Kazanian aquifer repeats a modern relief in a smoothed shape. The aquifer has no pressure within large river valleys, but in the watershed areas the excess pressure can reach 160 m.

The magnitude of groundwater discharge from the Lower Kazanian aquifer into river valleys can be determined using the law of A. Darcy:

\[ Q = T \times B \times I, \]

where \( Q \) is discharge rate (m³/day), \( T \) – transmissivity in zones of underground water discharge (m²/day), \( B \) – length of zone of underground water discharge (m), \( I \) – pressure gradient.

The discharge into the rivers is essentially a natural underground water resource. This can be calculated conveniently for separate drainage basins, isolated in terms of hydro geodynamic balance. Boundaries of such drainage basins are river valleys – main discharge zones, and surface water shedding lines, which correspond in the East-Kama region to underground watersheds of the Lower Kazanian sediments (Table 1). This basin-based method allows to localize the flow of underground water, quantifying its variability in space, and to visualize variations in modules of underground flow and underground mass flows of dissolved substances. These modules are calculated as follows:

\[ q_{uf} = Q / F \text{ and } q_{ds} = Q \times M / F, \]

where \( q_{uf} \) is the underground flow module (l/sec*km²), \( q_{ds} \) – module of the underground mass flow of substances dissolved in water (g/sec*km²), \( Q \) – flow rate of the Lower Kazanian aquifer (l/sec), \( F \) – catchment area (km²), \( M \) – mineralization of underground water (g/l), \( Q \times M \) – the amount of substances dissolved in water and carried by the filtration stream (g/sec).

**Results and Discussion**

The minimum value of the Lower Kazanian aquifer natural resources is 2141,000 m³/day (24.8 m³/sec). Given that the area of this aquifer is 17421.4 km² and the normal annual precipitation is ~500 mm/year, it is easy to determine that the flow rate is ~9% of the incoming...
atmospheric moisture. The value of effective precipitation under undisturbed conditions in some parts of the oil region is 15% [6]. If we assume that 2-3% of the incoming precipitation form the flow of the hydrogeological units overlying the Lower Kazanian aquifer, no more than 5% of the annual precipitation account for the recharge of the underlying units.

Table 1. Flow characteristics of the Lower Kazanian aquifer in the East-Kama region of the Republic of Tatarstan

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Whole East-Kama region</th>
<th>Areas of large oil fields</th>
<th>Areas of gypsum-free sections outside oil fields</th>
<th>Areas of gypsum-bearing sections outside oil fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of drainage basins</td>
<td>71</td>
<td>34</td>
<td>28</td>
<td>9</td>
</tr>
<tr>
<td>Area, km²</td>
<td>17421.4</td>
<td>6261.6</td>
<td>8913.7</td>
<td>2246.1</td>
</tr>
<tr>
<td>Length of discharge zones, km</td>
<td>2416.9</td>
<td>956.1</td>
<td>1231.9</td>
<td>228.9</td>
</tr>
<tr>
<td>Weighted mineralization of the underground water in discharge zones, g/l</td>
<td>0.4-2.6</td>
<td>0.4-1.73</td>
<td>0.4-0.82</td>
<td>0.4-2.6</td>
</tr>
<tr>
<td></td>
<td>0.68</td>
<td>0.8-1.0</td>
<td>0.4-0.6</td>
<td>0.8-1.2</td>
</tr>
<tr>
<td>Flow rate, thousand m³/day</td>
<td>2141.0</td>
<td>582.4</td>
<td>1408.7</td>
<td>149.9</td>
</tr>
<tr>
<td>Underground flow module, l/sec*km²</td>
<td>0.13-5.95</td>
<td>0.13-5.75</td>
<td>0.39-5.95</td>
<td>0.33-1.05</td>
</tr>
<tr>
<td></td>
<td>1.42</td>
<td>1.08</td>
<td>1.83</td>
<td>0.77</td>
</tr>
<tr>
<td>Amount of substances carried out by filtration flows, t/day</td>
<td>1292.25</td>
<td>463.13</td>
<td>654.3</td>
<td>174.82</td>
</tr>
<tr>
<td>Mass flow module of substances dissolved in water, g/sec*km²</td>
<td>0.09-2.71</td>
<td>0.09-2.57</td>
<td>0.16-2.71</td>
<td>0.18-1.66</td>
</tr>
<tr>
<td></td>
<td>0.91</td>
<td>0.89</td>
<td>0.95</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Note. In the numerical characteristics expressed in fractions, the numerator contains the range of fluctuations, the denominator – weighted average or prevailing values. The values of flow rate and modules are minimal, because spring runoff was not taken into account.

The fresh water flow rate of the Lower Kazanian aquifer is 1050.54 thousand m³/day; from the regionally weighted average of underground flow module of 1.42 l/s*km², the flow into recent rivers amounts for 1.29 l/s*km². For comparison, similar values (1005.97 thousand m³/day and 1.32 l/s*km² respectively) have been obtained in the late 1990s and early 2000s by the Tatar Geology and Prospecting Survey of JSC TATNEFT (V. Kuznetsov et al., 2002). The latter value is determined based on the areal hydrometric survey. Thus, our calculated data are very close to the results of field studies.

Our new data also allow to estimate the extent of the geological activity of groundwater in the Lower Kazanian aquifer. If the daily discharge of groundwater is 2141 thousand m³, the weighted average of mineralization in the discharge zones is 680 mg/l, that of meteoric waters is 20 mg/l, the area of the aquifer is 17421.4*10⁶ m² and the density of leached rocks is 2.4 g/cm³, a surface deepening of 10 m would take only 0.81 million years (this is the rate of underground chemical denudation).

Conclusions

Detailed lithological and stratigraphic investigations, supplemented by regular patterns of parameter changes of geofiltration and hydrogeochemical fields, allow us to obtain a number of interesting hydrogeological data, which are comparable to similar data obtained from specialized field studies. These results may be of interest both from the scientific point of view (identification of water-balance characteristics, the extent of the geological activity of underground water), as well as for a practical rational planning and exploration of underground drinking water.
REFERENCES

Changes in Structural Group Composition of Asphaltenes and Carbene-Carboinds of the Domanic Shale in Sub- and Supercritical Water: FT-IR Spectroscopy Data

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Abstract

This paper presents the results of a change in the structural-group composition of asphaltenes and carbonaceous substances such as carbene-carboinds in the products of the conversion of high-carbon Domanic rock from the sediments of the Semulukskoe-Mendimskoe horizon of the Volga-Ural petroleum basin, after exposure at temperatures of 320, 374 and 420 °C in sub- and supercritical water. IR Fourier spectroscopy showed that increasing the temperature to supercritical water conditions (374 and 420 °C) leads to chemical transformation of high molecular weight components and Domanic kerogen, accompanied by the formation of carbene-carboinds – polymerization and condensation products that differ from asphaltenes in a higher degree of aromaticity. The highest content of carbene-carboinds is observed in the composition of the products obtained from experiments at 374 °C, apparently associated with intensive decomposition of kerogen of Domanic rock. Increasing the temperature to 420 °C leads to the formation of coke-lake products as a result of oxidative degradation processes, which leads to a decrease in their content in liquid hydrocarbons.

Keywords: organic matter, Domanic rock, supercritical water, IR-analysis, asphaltenes, Volga-Ural basin

Introduction

Asphaltenes are important components of various fossil fuels, including heavy oils, coal, and oil shale. In Russia, the Bazhenov Formation in West Siberia and the Domanic formations of the Volga-Ural petroleum province are the analogues of shale rocks [1], [2], [3]. The horizons of Mendimskoe, Domanic (Semulukskoe) and Sargaevskoe from the Volga-Ural petroleum basin corresponds to the Domanic shale [4]. The Domanic shale rock is dark siliceous clayey bitumen limestone, with a content of organic matter (OM) up to 20% [5], [6]. A significant part of OM is insoluble kerogen.

The organic matter of shale rocks transforms under the hydrothermal influence and generates mobile hydrocarbons. A highly informative method to study the structural group composition of high molecular weight components of oil and OM rocks is IR Fourier Spectroscopy. This method allows evaluation of the conversion of various hydrocarbon and functional groups in both natural and man-made processes [7], [8].

This paper is an IR Fourier Spectroscopy study of chemical conversions of asphaltenes and coaly matters as a result of Domanic shale transformations in sub-and supercritical conditions (the temperature of which was 320, 374 and 420 °C).
Methodology

This study focuses on the Domanic shale rock from the Chishminskoe area of Semilukskoe-Mendimskoe horizon of the Volga-Ural petroleum province. The samples were extracted from the TVD of 1720 m. The Chishminskaya area is located in one of the largest oil fields of Tatarstan Republic – Romashkino.

Laboratory simulation was carried out in an autoclave reactor at temperatures of 320°C, 374°C, 420°C for 1 hours. Heat treatment was performed in an inert atmosphere (nitrogen) in the autoclave reactor with 300 ml capacity by Parr Instruments. The ratio of water-rock sample was 1:1. During the simulation, the pressure of vapor-gas mixture increased up to 17 MPa at 320°C, up to 24.6 MPa at 374°C and up to 24.4 MPa at 420°C.

Hot extraction with chloroform was applied on core material before and after exposure to thermal effect in a Soxhlet extractor. The extract’s composition (SARA analysis) was determined by liquid-adsorption chromatography on aluminum following the methodology recommendations developed by VNII NP, ASTMD4124-09 and GOST 32269-2013.

The structural group composition was determined by FTIR spectroscopy with Vector 22 IR spectrometer (Bruker) in the range of 4000-400 cm⁻¹ with a resolution of 4 cm⁻¹.

Results and Discussion

The group composition of products of hydrothermal experiments obtained in sub- and supercritical water at various temperatures is presented in Fig. 1. The initial sample of Domanic shale rock is characterized by a high content of high-molecular hydrocarbons: asphaltenes (29.0 wt %) and resins (37.0 wt %). The content of saturate (14.8 wt %) and aromatic (19.2 wt %) hydrocarbons are low. During hydrothermal treatment of Domanic shale rock in subcritical conditions (T=320°C and P=17 MPa) compared with the original rock, there is an increasing concentration of aromatic hydrocarbons to 22.7 wt % and asphaltenes up to 32.9 wt %.

However, the content of resin decreased to 27.1 wt % in contrast with the initial rock sample.

The supercritical condition of 374°C and 24.6 MPa has a special influence on the destruction of resins, the content of which is greatly reduced to 65%. The composition of the products of the experiments increases newly formed saturated hydrocarbons from 14.8 to 33.9 wt %.

Increasing the temperature of supercritical water up to 420°C reduces the content of asphaltenes and resins due to transition of hydrocarbons into saturate (36.2 wt %) and aromatic structures (32.6 wt %).

In the products of hydrothermal experiments obtained in supercritical water at 374°C and 420°C, the formation of insoluble high-carbon substances such as carbine-carboids is observed. This indicates the occurrence of the processes of destruction of asphaltenes and high molecular weight fragments of kerogen through the least stable heteroatomic bonds with the formation of both saturated and aromatic hydrocarbons and products of compaction such as carbonaceous substances.

The further study of asphaltenes and coal matters (carbene-carboids) was performed using IR Fourier Spectroscopy. The IR spectra of high-molecular products were compared by optical density at maximum corresponding absorption bands: formation of alkane at 720 cm⁻¹ (methylene group CH>4), 1380 cm⁻¹ and 1465 cm⁻¹ (CH3 methyl and CH2 methylene group); aromatic compounds at 1600 cm⁻¹ (C=C bond); oxygen containing compounds in carbonyl groups of acids at 1710cm⁻¹, in ester carboxyl groups at 1740 cm⁻¹ and sulfoxide groups 1030 cm⁻¹ [9].
Fig. 1. SARA-analysis of the initial extract and extracts after the transformation of Domanic shale rocks at sub- and supercritical conditions (320, 374 and 420 °C)

The spectrum of asphaltenes after treatment at 320°C (Fig. 1) is almost similar to the spectrum of initial asphaltenes. However, it differs strongly from the spectra of asphaltenes after 374°C in the higher intensity of absorption band, which is specific for aromatic structures (1600 and 900-730 cm⁻¹). In the given spectra, there is no absorption band for carbonyl structures (1710 cm⁻¹). The increase in intensity of 1450-1455, 1380 cm⁻¹ absorption bands is observed. It indicates an increase in the content of aliphatic structures of asphaltenes.

The IR spectra of asphaltenes from products at 420°C is characterized by a sharp increase in the intensity of the absorption band at 1250 cm⁻¹, 1100 cm⁻¹, which indicates the presence of an oxygen-containing group in esters and alcohols. The intensity of aromatic groups in the range of 900-730 cm⁻¹ is due to the vibration of four hydrogen atoms that are attached to the aromatic ring. In the given region, the intensity of absorption band was significantly decreased in contrast with the initial asphaltenes and the experiment after 320°C. The greatest decrease in the intensity of aromatic triplets in the range of 900-730 cm⁻¹ is observed in the spectra of asphaltenes after the transformation of Domanic rock in supercritical water at 374°C. The increase in intensity of 1710, 1030, 500-400 cm⁻¹ absorption bands indicate the increase of oxygen containing groups in their structure. Oxidative cracking processes are ongoing.

The spectra of carbenes-carboids (Fig. 2) obtained at temperatures of 374°C and 420°C do not have absorption bands of carbonyl group (1710 cm⁻¹), or esters (1740 cm⁻¹). The increase in temperature of supercritical water up to 420°C increases the absorption bands of 720-900, 1640 in spectral curve of high-organic matter, which is characterizes the aromatization degree; 1435, 1380 cm⁻¹ paraffinic degree and 1030 cm⁻¹ sulfurization degree.
The observed changes in the structure of asphaltenes and carbenes, carboids of the products of hydrothermal transformations of Domanic rock are reflected in the spectral indices presented in Table 1. For comparison of the products under study, the following spectral coefficients associated with the structural group composition were used: $C_1 = D_{1600}/D_{720}$ (aromaticity), $C_2 = D_{1710}/D_{1465}$ (oxidation), $C_4 = (D_{720} + D_{1380})/D_{1600}$ (paraffinicity) and $C_5 = D_{1030}/D_{1465}$ (sulfurization) [10]. The values of spectral coefficients are presented in the table.
Table 1. The structural-group composition

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Absorbance A at maxima of absorption bands at ν, cm⁻¹</th>
<th>*Spectral indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>1740</td>
<td>1710</td>
<td>1600</td>
</tr>
<tr>
<td>Asphaltene from rock extracts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>0.07</td>
<td>0.16</td>
</tr>
<tr>
<td>320°C</td>
<td>0.06</td>
<td>0.14</td>
</tr>
<tr>
<td>374°C</td>
<td>0.03</td>
<td>0.06</td>
</tr>
<tr>
<td>420°C</td>
<td>0.13</td>
<td>0.28</td>
</tr>
<tr>
<td>Carbenes and Carboids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>320°C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>374°C</td>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>420°C</td>
<td>0.04</td>
<td>0.11</td>
</tr>
</tbody>
</table>

In asphaltenes of the initial samples, the content of aliphatic hydrocarbons is very low and high amount of aromatic structures. This is observed in the low value of paraffin (2.48) and high aromaticity value C1 (0.86). The thermal influences on the Domanic shale in sub- and supercritical conditions effects the intensity of aromatization process that can be observed by the increasing index of aromaticity up to 0.98 at 320°C and 0.92 at 420 °C. The aromatization process is carried out due to the deficiency of atomic hydrogen in the system that is necessary for hydration of generated reactive radicals. The indices are increased from 0.21 to 0.51 for oxidation (C2) and from 0.86 to 0.92 for sulfurization (C5) under hydrothermal influence at 420 °C.

Conclusions

The investigations performed on the transformation products of high-organic Domanic shale rocks from Semilukskoe-Mendimskoe deposits of the Volga-Ural petroleum province using the IR-Fourier spectroscopy method revealed their composition and structure. With an increase in temperature to supercritical water conditions (374 and 420 °C), the formation of polymerization and condensation products of hydrocarbons (carbene-carboinds) is observed. These carbonaceous substances, characterized by a high degree of aromaticity, are formed from asphaltenes or kerogen fragments as a result of the breaking of heteroatomic bonds with the separation of substituents. The highest content of carbenes and carboids is observed in the composition of the products of experiments obtained at 374 °C, apparently associated with intensive decomposition of kerogen of Domanic rock. With an increase in the experimental temperature to 420 °C, the formation of coaly matters is accompanied by oxidative destruction processes, which leads to a decrease in their content in the composition of liquid hydrocarbons.

The results of IR spectroscopy indicate the occurrence of oxidative cracking of hydrocarbons under supercritical water conditions: asphaltenes become more oxidized, and carbeno-carboinds more aromatic.

Acknowledgements

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Voltzialean Conifers from the Kuedinskije Kluchiki Locality (Kazanian =Wordian) of the Urals, and their Morphological Interpretation

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Abstract

This paper discusses the characteristics of Voltzialean conifers from the Permian deposits of the Cisuralia and the Volga Region. These plants are attributed to the genus \textit{Archaeovoltzia} Naugolnykh in open nomenclature. The flat seed-scales with three lobes (one apical lobe and two lateral lobes with the additional lobing of second order) are characteristic of that genus.

The seed-scales formed the fertile zones, which were disposed on the ultimate leafy shoots.

Keywords: Permian, Urals, conifers, Voltziaceae, seed-scale morphology, fertile zones

Introduction

The conifer forest biome appeared in the Late Palaeozoic, and this event became an important factor in further evolution of the biosphere of the Earth. The first well-dated and well-defined conifers were recorded at the very beginning of the Middle Carboniferous. The first conifers consisted of one family, Walchiaceae (= Utrechtiaceae, Lebachiaceae, Lebachiellaceae) and its close evolutionary derivatives, the taxonomic status of which is a subject of ongoing paleobotanical debate. A new family with significant morphological innovations, belonging to a new order of conifers, appeared in the second half of the Permian period, i.e. the family Voltziaceae Arnold of the order Voltziales Andreanszky. Voltzialean conifers became dominant in many Late Permian and Triassic floras throughout the world [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [16], [17]. Despite a large number of publications on this plant group (see references above and further discussion there), the origin of the family Voltziaceae is not absolutely clear. In general, it is clear that the flat seed scales, which are typical of this conifer group, were formed by fusion of the sterile scales and seed stalks of conifers belonging to the family Walchiaceae. This conclusion was expressed very explicitly by S.V. Meyen [7], who emphasized that Voltziaceae is different from Walchiaceae in forming seed scales by fusion of “monosperms” (seed-stalks) on the adaxial surface of a lateral “polysperm” (terminology after, e.g., [7], [8], [9]).

Which genera and species can be interpreted as intermediate forms between advanced Walchiaceae and the most primitive Voltziaceae? This question can be answered (at least, partly) by studying the conifers from the uppermost Lower Permian and the Middle Permian deposits of the Cis-Urals and adjacent regions.

Voltzialean Conifers of the Cis-Urals

Conifers conditionally assigned to the genus \textit{Voltzia} were described in several works based mostly on the sterile leafy branches from the Permian deposits of the Urals (see, for instance,
The main reason for such attribution was general (gross) morphology of the long linear leaves, similar to the leaves of Voltziaceae from the Upper Permian and Triassic deposits of Europe [2], [3], [14], [15], [16]. Some doubts have been expressed on the correctness of such a taxonomic attribution [9]. The exact taxonomic position of most of the conifers of “voltzialean appearance” is uncertain because of the absence of male and/or female reproductive organs that can be attributed to the same parent plants. Some of them could belong to the family Bartheliaceae Rothwell and Mapes [12].

It has been believed for a long time that true Voltziaceae is absent in the Lower Permian deposits of the Cis-Urals. But several seed-scales similar to the genus Pseudovoltzia Florin were found by step-by-step collecting of plant fossils in a number of Lower Permian localities in this area (Krasnaya Glinka, Krura Katushka-1, Krutaya Katushka-2, Chekarda-1: [12]). Almost the same type of seed-scales of voltzialean affinity were reported from the Lower/Middle Permian floras of North America [1].

Later, male cones Uralostrobus voltzioides Naugolnykh were described from the Lower Permian (Artinskian and Kungurian) deposits of the Southern and Middle Cis-Urals [11]. These conifer male cones are very similar to the cones of “classic” Voltziaceae from the uppermost Permian and Triassic of Europe, both in macromorphology and in the type of in situ pollen.

Re-examination of several fertile specimens of Lower Permian (Kungurian) conifers of the Cis-Urals shows that some of them should be attributed to a new genus Archaeovoltzia Naugolnykh [12]. This genus is different from the closely related genus Voltzia Brongniart in having more numerous seeds per seed-scale (three or more) and much more developed bracts.

Comparison with the other closely related genera, such as Pseudovoltzia Florin, Concholepis S.Meyen, Majonica Clement-Westerhof, Lebowskia Looy, Manifera Looy and Stevenson, and Dolomitia Clement-Westerhof is published in the protologue of Archaeovoltzia [12, p. 172].

Thus, it was discovered that voltzialean conifers in the strict sense (the family Voltziaceae) already existed in the Cis-Urals in Artinskian and Kungurian time. This statement supports initial ideas expressed by M.D. Zalessky on the possible presence of Voltziaceae in the Lower Permian (e.g., Kungurian, or = Bardian according to M.D. Zalessky) of the Cis-Urals [18], [19].

Additional collecting of plant fossils from the stratigraphically younger deposits of the Cis-Urals, specifically the Kuedinskie Kluchiki locality shows that the closely related conifers also existed in this region in the Middle Permian (Kazanian = Wordian). The Kuedinskie Kluchiki locality is near the City of Kueda (Chernushka district of the Perm region), and is characterized by rich paleofloristic and paleofaunistic assemblages. Faunistic assemblage of the Kuedinskie Kluchiki locality includes insects, fishes (Palaeonisciformes), amphibians (Discosauriscidae and Melosaurida), and reptiles. The fossil flora of this locality includes equisetophytes of the order Equisetales, peltaspermalean pteridosperms Compsopteris longipinnata Naug. (in manuscr.), ginkgophytes, vojnovskyaleans, and conifers. The conifers of the Kuedinskie Kluchiki locality are represented by several forms, including at least one species attributable to the genus Archaeovoltzia Naug., which the current author believes represents a new species of that genus.

Observations

Archaeovoltzia sp. from the Kuedinskoe Kluchiki locality is characterized by the structure of fertile/reproductive organs (Figs. 1, 2) and sterile leafy shoots. The material in hand includes ten specimens of leafy shoots with relatively thick axes of the last order and long linear needle-like leaves are arranged on the axes in relatively irregular spirals. The only exceptions are the apical parts of the leafy shoots, which have densely arranged leaves forming a brush-like pattern.
The female reproductive organs of the voltzialean conifer from the Kuedinskie Kluchiki locality are represented by fertile zones, which are disposed in the middle part of the last order shoots. The fertile zones are formed by densely arranged spirally disposed seed-scales. The seed-scales are similar to the seed-scales of the genus *Pseudovoltzia* Florin, but nonetheless have some peculiar morphological characters, which prevent this conifer from being attributed to *Pseudovoltzia*.

The seed scales are of subrombic to subtriangular shape, with three well-defined lobes. One lobe (axial or apical) is longer, while side (marginal) lobes are shorter. The size of the seed scales varies in a narrow range and is on average 6 mm long and 4-5 mm wide. The margins of the lobes are dissected into smaller lobes of the second order (this is not characteristic of *Pseudovoltzia*). There are three small seed scars of ovoid shape, disposed on the adaxial surface of the seed scales. The seed scars are located in the proximal part or in the mid-part of the lobes (one scar per lobe). There is a small scar of vascular tissues, positioned in the center of a seed scar. Seeds of ovoid shape with thin, narrow sarcotestal wings are often found together with leafy shoots and fertile zones of *Archaeovoltzia* sp. in the Kuedinskie Kluchiki locality. Most probably these seeds belonged to the same parent plant.
Fig. 2. *Archaeovoltzia* sp. Interpretative reconstruction of the upper part of the fertile zone (A), seed-scales (B, with the seeds in attachment; C, without seeds, seed-scars are visible), diagrammatic section through the fertile zone (C), and a part of the fertile zone with the clearly visible seed-scale (E; marked by an arrow).

The locality Kuedinskie Kluchiki, Perm region; Middle Permian, Kazanian (=Wordian). Abbreviations: S – seeds; SSc – seed scars on adaxial surface of the seed-scale. Scale bar is 1 cm (A); 5 mm (B, C, E). D – without scale.
Conifers and Insect/Plant Interaction

The conifers of voltzialean affinity demonstrate a closer position of the seeds in contrast to the more open position of the seeds typical for conifers belonging to the family Walchiaceae and its close relatives and derivatives. Seeds of both Walchiaceae and Voltziaceae were inverted, i.e. their apical (micropylar) parts were orientated towards the axil of the seed scale.

When the position of the seeds is more or less open, it is easy to transport pollen to the micropylar area of the seed just by the wind. Therefore, taking into account the well-developed air-balloons of the pollen of Walchiaceae, it is fairly obvious that conifers of the family Walchiaceae were wind-pollinated. In the case of Voltziaceae the situation is more complicated, because normally the seed-scales protected the seeds/ovules very effectively and almost completely covered the unfertilized ovules. Thus, it is possible that at least some of the conifers of voltzialean affinity were insect-pollinated or used a mixed type of pollination. Records of feeding activity of insects on conifer seeds in Cisuralia during the Permian [13] can be interpreted as possible initial coadaptation of early conifers and some insects.

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Interregional Correlation of the Base of the Serpukhovian Stage (Mississippian): Problems and Prospects

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Abstract

A review of the proposed markers for the base of the Serpukhovian has shown that their entries are not consistent in different sections, especially when they are not controlled by other fossil groups. The diagnosis and interspecific relations in the genus Lochriea of the conodont species L. ziegleri, the primary candidate marker, needs to be reassessed and it needs to be decided which morphotype is the best marker. The first occurrence levels of the marker foraminiferal species, especially J. delicata and N. postrugosus, need to be agreed, and the taxa from the critical levels need to be illustrated before a decision can be made on the boundary choice.

Keywords: Viséan-Serpukhovian boundary, GSSP, ammonoids, conodonts, foraminifers

Introduction

The base of the Serpukhovian Stage is one of the high priority tasks of the Subcommission on Carboniferous Stratigraphy (SCCS). In the type Serpukhovian Region in the Moscow Basin this boundary has traditionally been drawn at the base of the Tarusian Regional Substage [1] at the regional subaerial unconformity surface [2], [3]. The basal beds of the Tarusian contain ammonoids of the genus Cravenoceras and the base of the Tarusian is traditionally correlated with the base of the Pendleian (E1) of Great Britain and with the base of the Lower Namurian of Belgium and Germany [4]. However, this lithological boundary cannot be accepted as an International Standard, such as a GSSP. Therefore, for substantiation and correlation of this boundary outside the type region, it is necessary to recognize marker taxa and select a new section, in which the first appearance datum (FAD) of a proposed boundary marker would be able to be traced in a continuous phylogenetic lineage. Several markers have been proposed, including conodonts, foraminifers, and ammonoids, but there are only few sections that are known to contain all three groups [5].

The following problems currently prevent the definition of the base of the Serpukhovian.

1. Some of the proposed taxa (e.g., the conodont Lochriea ziegleri Nemirovskaya, Perret and Meischner) appear below the traditional base of the Serpukhovian.
2. The appearance of some indicative taxa does not seem to be isochronous. For example, the foraminifer Janischewskina delicata (Malakhova, 1956), Neoarchaediscus postrugosus (Reitlinger, 1949), etc. have been reported from the “Brigantian” (i.e.,
uppermost Viséan) of Western Europe, although they appear in the Tarusian of the type area.

3. Ammonoids that have originally been used to mark the base of the Pendleian in the UK and the Lower Namurian in Germany are not found outside Western Europe. The ammonoid species *Cravenoceras leion*, which was originally thought to be the boundary marker, is not found outside the type area in the British Isles, and the species *Edmooroceras pseudocoronula* (Bisat, 1950) is only found in Germany, northern England, and Ireland.

4. The taxonomic concept of the major candidate, the conodont species *Lochria ziegleri*, is not developed, and this species is not confirmed from North America.

5. Deep-water and shallow-water successions of the boundary interval cannot currently be reliably correlated.

Below we will discuss these problems in greater detail and outline possible prospects for defining the boundary in the near future.

**Problems in Identifying the Base of the Serpukhovian**

1) In the type Serpukhovian areas, in the Novogurovsky Quarry, the FOD (First Occurrence Datum) of *L. ziegleri* is established in the shallow-water limestones of the upper half of the Venevian (middle part of sequence VN2, Unit 23) [3]. However, the specimens of *L. ziegleri* from VN2 are derived, so the FAD (First Appearance Datum) of this species should be expected lower in the section [5].

   It is clear that the first occurrence of *L. ziegleri* is below the base of the type Serpukhovian and its equivalents [6], and a decision should be made whether lowering the base of the Serpukhovian is an appropriate measure, or whether a marker should be sought among other taxa appearing nearer to the traditional boundary. Because of the traditional correlation of the basal Tarusian with the basal Namurian, Pendleian, and Kosogorian, this decision has to take into account changes that might affect regional scales in Belgium, UK and other areas, which will lead to objections by some authors [7]. In the Dombar Section in the Mugodzhary Region of the South Urals, the entry of *L. ziegleri* was recorded within the *Hypergoniatites-Ferganoceras* Genozone, the topmost in the Upper Viséan succession of the South Urals [8].

   Similar results were obtained in the Verkhnyaya Kardailovka Section on the eastern slope of the South Urals where *L. ziegleri* first appears in the interval 19.53-19.63 m (*L. cruciformis* appears in the interval 19.63-19.72) from the base of the section, which is below the entry of *Ferganoceras constrictum* Nikolaeva and Konovalova, 2017 at 20.8 m from the base of the section [9], [10]. In the Wenne Section (Rhenish Massif, Germany) the FOD of *L. ziegleri* was reported from the Upper Viséan *Lyrogoniatites suerlandense* Zone [11], but this morphotype does not belong to this species [12]. It is more difficult to correlate the entry of *L. ziegleri* with foraminiferal markers because both are facies dependent, and in basinal sections indicative foraminifers are scarce or absent.

2) Among foraminifers, several species have been proposed as possible markers, the main candidates were *Janischewskina delicata*, *Endothyranopsis plana* Brazhnikova in Brazhnikova *et al*., 1967, *Planonendothyra* ex gr. *ajutovica* (Reitlinger, 1950), *Eostaffellina decurta* (Rauser-Chernousova, 1948), *Neoarchaediscus postrugosus*, *Eolasiodescus donbassicus* Reitlinger, 1956, *Monotaxinoideus gracilis* (Dain in Reitlinger, 1956) [13], [14], [15]. The FADs of these taxa do not seem to be consistent. For instance, *Janischewskina delicata*, *Plectomillerella tortula* (Zeller, 1953), *Planonendothyra* sp., and *Endothyra phrissa* (Zeller, 1953), were reported ca. 6 m above the base of the Venevian (middle of sequence VN2, Unit 23) [3], but this still needs to be confirmed, because in Zaborie (Moscow Basin) it is recorded from the Tarusian and in the Khudolaz Section from the Sunturian (see references in [5]). Vdovenko in [1] cited
Janischewskina sp., Janischewskina ex gr. typica, Janischewskina ex gr. rovnensis (Ganelina, 1956) from the Moscow Basin. However, their distribution was not clearly shown. *J. typica* was illustrated ([1], pl. XVII, Fig. 3) from Sample G-15-16, which according to [1], p. 78, text-fig. 35, is approximately in the middle of the Tarusian in the Gurievsky Quarry, Tula Region, Moscow Basin. No *J. delicata* was illustrated. Gibshman et al., [2] illustrated *J. delicata* in pl. 5, Figs. 17 and 18 (Sample 14/40, Bed 25, Lower Tarusian); and *J. typica* in pl. 5, Fig. 13 (Sample 14/40, Bed 25). In the same publication *J. delicata* is shown in text-fig. 4 to occur in the middle of Bed 23, Sample 13/40, in the upper part of Bed 23, Sample 13/42, in the middle of Bed 24, Sample 13/43 (all Venevian), then near the base of Bed 25, Sample 14/40, middle of Bed 25, Sample 14/41, upper part of Bed 25, Sample 14/42, all Tarusian, and then in the Protvian. However, the description of the succession in the Novogurovsky Quarry mentions ([2], p. 22) the presence of *J. cf. delicata* in Beds 23 and 24, and *J. cf. typica* and *J. delicata* are reported from Bed 25. These discrepancies need to be clarified.

*Neoarchaediscus postrugosus* in the Moscow Basin and Izyayu River (Subpolar Urals) enters in the basal Serpukhovian (i.e., in the Tarusian) [5], [16]. However, it has been reported from the Brigantian and its equivalents in British Isles and Morocco [17], [18] and Spain [19], [20]. In the Ladeinaya Gora Section in the Middle Urals, where *Lochriea ziegleri* is recorded in Bed 17, *Neoarchaediscus postrugosus* appears 1.5 m below it, at the base of Bed 17, Sample 17.3; and in the Mariinsky Log Section *Neoarchaediscus postrugosus* enters at the level of Sample 3c.3 in Unit 3b, 3 m above the FOD of *L. ziegleri* [21], [22].

*Monotaxinoides gracilis* is recorded in many regions and it is more or less associated with the Serpukhovian, appearing somewhat above the entry of *L. ziegleri* (Canalón Member of the Alba Formation, basal unit in the Vegas de Sotres Section, Cantabrian Mountains, Spain) above the level of the first appearance of *L. ziegleri* [19]. In the South Urals, in the Suleimanovo Section, it is also found ca. 4 m above the base of the Serpukhovian, probably in the equivalents of the Steshevian (the base of the stage is drawn by the appearance of *Eostaffellina decurta* [23]). In the Muradymovo Section, also South Urals, *M. gracilis* is found in the Yuldybaevian Regional Substage [24]. Summaries of the proposed foraminiferal markers published by [5], [25] and [41] showed considerable discrepancies in their FODs. It has been proposed to use two zonal foraminiferal schemes for the inner and outer shelf [25]. The summaries have suggested that the taxonomy of the key taxa and their detailed records need to be re-examined and published in greater detail.

(3) The base of the Serpukhovian in the British Isles was traditionally considered to be close to the base of the Pendleian Stage. Originally the Pendleian Stage was proposed by [26], and was approximately based on the E1 succession of the Bowland Shales of Pendle Hill (northern England), where the occurrence of the ammonoid *C. leion* was mentioned. However, the level of *C. leion* on Pendle Hill was not extensively studied [27] and its position has not been confirmed. A detailed succession of this interval was described from Slieve Anierin (= Sliabh an Iarainn, Ireland) [28], but because *C. leion* was found in at least two faunal horizons, the exact position of the boundary was not clear. Korn and Tilsley [29] reported *C. leion* from Derbyshire (England), but from a younger ammonoid assemblage than the original finds.

Although the potential of the ammonoid genus *Cravenoceras* for the definition of the base of the Serpukhovian is not exhausted [4], it is not possible at present to use it for precise stratigraphic correlations. The use of *Edmooroceras pseudocoronula*, also proposed for correlations [30] is not currently feasible because this species is not found outside Western Europe [4]. It is possibly more practical to focus on ammonoids appearing below the base of the classical Serpukhovian and the base of the Pendleian and their equivalents. Recent discovery of the ammonoid genus *Ferganoceras* in Verkhnyaya Kardailovka [31] and Morocco [32] revealed the presence of levels comparable with the Nm1a level of [31] (= topmost Viséan).
This is significant because the FOD of *L. ziegleri* was recorded 0.67 m below the bed with *Ferganoceras* in Verkhnyaya Kardailovka [10] and 80 cm above the bed with *Ferganoceras* in the Dombar Hills, while the FOD of *Ferganoceras* in Dombar is in the *L. nodosa* Zone [7].

Beds with *Ferganoceras torridum* in Morocco belong to the uppermost beds of the Zrigat Formation, which reportedly ranges in the *L. nodosa* Zone [32].

**Plate 1**

![Plate 1](image)

Plate 1. Marker taxa for the Visean-Serpukhovian boundary.

**Figs. 1-5.** *Lochriea ziegleri* (Nemirovskaya, Perret and Meischner): (1, 2) Verkhnyaya Kardailovka Section, South Urals, Russia; (1) specimen 244/2013; interval 19.63–19.72 m; (2) specimen 244/2014; interval 19.63–19.72 m; scale bar = 100 μm; (3-5) Serpukhovian of the Mariinsky Log Section, Middle Urals, Russia; the specimens are housed in the Department of Regional and Oil and Gas Geology, Faculty of Geology, Perm State University, Perm, Russia; (3) Unit 1, Sample 1-1; (4) Unit 2, Sample 2.1; (5) Unit 1, Sample 1-1; scale bar = 100 μm; ([5], text-figs. 8a-8c); **Figs. 6, 7.** *Ferganoceras elegans* Ruzhencev and Bogoslovskaya, 1971, specimen PIN, no.
The following sections have been proposed as possible GSSP candidates for the base of the Serpukhovian: (1) Verkhnyaya Kardailovka on the eastern slope of the South Urals [9, 10, 39], Naqing section [36, 37, 40], Wenne Section (Rhenish Massif, Germany [11], and Vegas de Sotres [19]. The Verkhnyaya Kardailovka section represents a condensed deep-water succession with multiple fossils, but there are only a few useful foraminifers, and representatives of Lochriae are still not fully described and photographed, so only a few
specimens have been illustrated. The Naqing Section produced many records of well-illustrated conodonts, but no ammonoids have been reported. Occurrences of the foraminifers Janischewskina delicata and Bradyina ex gr. cibrostomata reported from 2.15 m above the entry of L. ziegleri [37] have not been illustrated. The Wenne Section contains numerous ammonoid horizons and many conodonts, but no foraminifers, and there is no agreement about the identification of primitive L. ziegleri [5]. The Vegas de Sotres section consists of several isolated outcrops, with no ammonoids.

Conclusions

In the current situation, a decision about the boundary marker and the candidate sections seems premature. It is most important from our point of view to complete the study of conodonts from the Verkhnyaya Kardailovka Section, to revise the taxonomy of the genus Lochria, and to update foraminiferal records from the Novogurovsky Section. It is also important to revise identifications and taxonomy of the key foraminiferal taxa and illustrate the most significant occurrences.

Acknowledgments

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Zircon Mineralogy, Rock Composition and Dating of the Archean Complex of the Eastern Pechenga Structure (Kola Region)

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Abstract

This article provides a geological review of the outcrops located in the NW part of the Central-Kola terrain of the Kola region. The garnet-biotite and biotite gneisses are the most ancient rocks in the region. The gabbroids are currently represented by metamorphosed and boudinage amphibolite bodies are emplaced in the gneisses. Quartz metasomatizes are developed along the contact between the gneisses and amphibolite’s; there are also granodiorites, pegmatite and aplite veins. The following generations of zircons are distinguished in the rocks: metamorphic in the gneisses, magmatic and metamorphic in the metamorphic gabbro, and metamorphic and metasomatic in the quartz metasomatize. The following age sequence of geological processes has been established by U-Pb zircon dating:
2.8 Ga – the time of the garnet-biotite gneiss metamorphism; 2722±9 Ma – the granodiorite crystallization time; 2636±41 Ma – the plagioaplite emplacement age and 2620±6 Ma – the age of the origin of pegmatites marked the final stages of Archean evolution; 2587±5 Ma – the age of gabbroid emplacement and 2507±7 Ma – the origin time of the quartz metasomatism, interpreted as the age of gabbro and biotite gneiss metamorphism.

Introduction

The ancient metamorphic rocks that developed at the north-western margin of the Pechenga structure in the Central Kola terrain [1] are the basement for both the Pechenga ore and the Litsevsky uranium ore regions (Fig. 1). The study of the terrain characterized by the wide development of iron ore formations is of interest for the understanding of their genesis. There are several theories on the origin of iron quartzites. These include sedimentary [2], metasomatic [3] and synergistic [3], [4] explanations of their formation. Earlier [5], [6] these rocks were considered to be homologs of rocks discovered by the Kola superdeep well, and thus the studied areas were mapped in detail.

The Central Kola terrain is composed of granite-gneisses and migmatites with relics of biotite-plagioclase, biotite-amphibole-plagioclase gneiss, amphibolite, garnet-biotite-plagioclase gneiss [1], [7]. The age of the earliest metamorphism of the Kola series is 2830±10 Ma, the age of the last metamorphism is 2760±10 Ma; the age of the protolith of gneisses is 2925 Ma [8]. The garnet-biotite gneisses by the structural-metamorphic scale [5] are the most ancient rocks in the Pereval, Polygon and Malonemetskaya Bay outcrops, with quartz metasomatites (iron quartzites) forming along their contact with the metamorphosed gabbroids. Also, granodiorites with an age of 2722±9 Ma [6] occur within the Malonemetskaya Bay exposure, cut by pegmatite veins.

The aim of the present research work is to determine the age sequence of the geological processes for the Pereval, Polygon and Malonemetskaya Bay outcrops.
Methods

Various zircon grains and generations were selected from monomineral fractions. The morphological types of the zircon crystals were distinguished by the following features: appearance, habit, coefficient of elongation of crystals, colour, and transparency. The zircon generations were identified during the study of the internal structure of the crystals, such as zonality, cores, shells, as well as the development of forms of crystals during growth [9].

Further, isotopes of lead and uranium were extracted from each sample according to the method [10]. U and Pb isotope measurements were made on an MI-1201T mass spectrometer in the Laboratory of Geochronology and Isotopes Geochemistry GI KSC RAS, usually, on a smoothly falling ion current; the measurement error of the Pb isotopic composition was 0.15%; idle intra-laboratory contaminations of the full analysis were less than 0.2 ng for lead and 0.05 ng for uranium. The ages were calculated based on the accepted values of the uranium decay constants; all errors are reported at the 2σ level. All isotopic ratios were corrected for mass discrimination by [11] and equal to 0.18±0.05%. The isochron parameters were calculated in the program [12].

Geological Setting

The garnet-biotite and biotite gneisses of sub-latitudinal stretch are located within the Pereval outcrop. Metamorphosed and boudinage gabbroid bodies represented by feldspar amphibolite’s lie in the gneiss, parallel to its foliation.
The quartz-magnetite and quartz-silicate (quartz-pyroxene, quartz-amphibole with garnet and without one) metasomatic rocks are situated along the contact of the metagabbro and garnet-biotite gneisses. The aplite’s cut the metagabbro. The granite pegmatite boudinage bodies are located along the strike of the shale-like garnet-biotite and biotite gneisses. The metadolerite dykes are the youngest rock in the outcrop, with sub-latitudinal and sub-meridional strike.
The alternating gray-white granites and garnet-biotite gneisses with layers of staurolite-garnet-biotite gneisses are exposed on the Polygon outcrop. The thickness of the granite layers varies from 15 to 40 meters. The thickness of the garnet-biotite gneisses layers is 15-50 meters. Lenses of garnet-biotite gneisses 3 m thick are located inside the plagiogranite in the central part of the outcrop. There are zones of silicification of these gneisses and also quartz veins with garnet among the garnet-biotite gneisses near the contact of the rocks. The silicification zones are the zones of appearance of the most intensely tectonic processes. The granite pegmatites with a north-western strike cut the gneisses. The thickness of the pegmatite is 1.5-2 meters. It is assumed gneiss silicification is associated with the granitization process.

The Malonemetskaya Bay outcrop consists of migmatized biotite-amphibole and biotite gneisses with beds of banded iron formation. All these rocks were metamorphosed under conditions of amphibolite and epidote-amphibolite facies, while the surrounding garnet-biotite and alumina gneisses outside the outcrop were metamorphosed under conditions of amphibolite to granulite facies. The veins of aplite and pegmatite cut the rocks of the outcrop. Granodiorite occurs at Malonemetskaya Bay, with an age of 2722±9 Ma [6].

**Sequence of Endogenous Processes and Deformation Stages, Sampling and Petrography of Samples**

The sequence of endogenous and deformation processes is determined by the following stages. The original alternation of biotite, garnet-biotite, staurolite-garnet-biotite gneisses is considered to be preliminary banding. Shale, fine and coarse migmatitic banding occurred during the first deformation stage. During the second stage the migmatite banding was wrinkled into folds, and pegmatite intruded parallel to the axial planes. The gabbroid were emplaced between the second and third stages of deformation. The granites intruded during the third stage of deformation; and the garnet-biotite, biotite gneisses and gabbroids were split and boudinaged together. The gabbroids were transformed into amphibolites. The magnetite-silicate rocks were
formed along the shear zones marking the boudins, inside the bodies of the metamorphosed gabbroids. The magnetite-quartz, magnetite-amphibole, and magnetite-pyroxene rocks were formed along the contact between the gabbroids and gneisses. The coarse-grained pegmatites intruded after the third stage of deformation, cutting the boundaries between amphibolite lenses. The coarse-grained microcline-containing aplites were formed, and deformation of gneiss, pegmatite and granite occurred during the fourth stage. During the last, final stage, metadolerite dikes intruded through a network of sub-latitudeal and sub-meridional cracks.

The garnet-biotite gneisses (sample VII – 12 kg) were collected in the southern part of Pereval outcrop, and the metamorphosed gabbroids (sample II – 27.7 kg) were collected in the central part of the boudinaged metagabbro body. The quartz metasomatites (sample III – 25.3 kg I) were selected in the north-western part of the Polygon outcrop at the contact of amphibolite and garnet-biotite gneisses. Plagioaplite (sample A-1 – 2.5 kg) and pegmatites samples (sample P-1 – 3.2 kg) were selected at the Nemetskaya Bay outcrop.

The garnet-biotite gneiss (VII) has a schist texture and a lepidolminoblasic texture and consists of (Fig. 2) quartz grains (40%) from 0.15 mm to 0.45 mm in size; biotite lamellae (20%) with size 0.06-0.6 mm formed a fine-flaked mass; plagioclase grains (20%) with sizes ranging from 0.3 mm to 0.9 mm were replaced by epidote and chlorite; garnet grains (10%) from 0.6 mm to 3 mm in size were replaced by chlorite and biotite through fractures; clusters of prismatic kyanite crystals (3%) and staurolite (3%), as well as muscovite (3%); ore mineral (1%); zircon grains (single characters) 0.03 mm in size.

The metamorphosed gabbro (II) with massive texture and nematoblastic structure composed of (Fig. 2) amphibole grains (85%) ranging in size from 0.3 mm to 3 mm; and colorless grains of plagioclase (15%) from 0.2 mm to 0.25 mm in size.

The quartz metasomatite (III) has a schist texture and granoblast texture and consists of (Fig. 2) quartz grains (60%) with size from 0.3-3 mm; elongated cummingtonite (15%) replaced by amphibole near the ore mineral in some places; orthopyroxene grains (10%) from 0.5 mm to 1.5 mm in size replaced by cummingtonite; ore mineral (5-10%) formed at the contact between quartz and cummingtonite.

The fine-grained plagioaplites (Fig. 2) have allotriomorphic structure and consist of quartz (40%), plagioclase (55%), and biotite (5%). The pegmatites (Fig. 2) are rock with a porphyroblastic structure, consisting of quartz (65%) and plagioclase (35%).

Fig. 3. Zircon morphology and internal structure
Zircon Mineralogy and U-Pb Dating

Two generations of zircon grains (Fig. 3) were recognized in the biotite plagiogneiss sample (VII): prismatic crystals with a complex internal structure and the metamorphic homogeneous prismatic crystals and shells over the earlier crystal grains. Three points of the metamorphic zircon yielded an age of 2810±150 Ma. This age is preliminary and evaluated for 3 points only, and interpreted as the time of metamorphism of the garnet-biotite gneisses.

Three generations of zircon (Fig. 3) were noted in the metagabbro sample (II): magmatic pink prismatic crystals with uneven faces; metamorphic brown crystals of short-prismatic habit with developed irrational faces; and metamorphic pink homogeneous zircon. The discordia for three data points of the magmatic zircon (Fig. 4a) has the upper intercept with the concordia at 2587±5 Ma, corresponding to the gabbro emplacement time. The U-Pb upper intercept age for the metamorphic zircon (three data points) (Fig. 4a) is equal to 2507±7 Ma and corresponds to the time of metamorphism of the gabbro.

There are 3 generations of zircon (Fig. 3) in the quartz metasomatize sample (III): the xenogenic amphibolite zircon, the metamorphic prismatic (pink homogeneous crystals) and the metagmorphic pink isometric (formed with an excess of silica and iron additives). Three data points of the metamorphic zircon and three data points of the metasomatic zircon (Fig. 4b) yielded ages correspondently 2503±67 Ma and 2522±53 Ma interpreted as the time of the origin of the quartz metasomatites.

The Zr/Hf ratios of zircons in the biotite gneisses vary from 41.41 to 49.46, in amphibolites, zircons are 44.4-45.1; in quartz metasomatites, zircons are 48.42-60.27; these correspond to the average Zr/Hf ratios of zircon in all rocks of these types.

Two generations of zircon (Fig. 3) were distinguished in the plagioaplite sample (A): the bulk of the sample (85%) consists of pinkish, long and short prismatic hyacinth type crystals. In a smaller amount – up to 15% – long, brown prismatic crystals are present. The age of 2636±41 Ma is obtained for five fractions of pink zircon (Fig. 4c), corresponding to the age of the plagioaplite.

The short prismatic zircon crystals (Fig. 3) were distinguished in the pegmatite (P). The color of zircon varies from colorless to yellow and brown. The zircon age (Fig. 4c) for five data points is equal to 2620±16 Ma and corresponds to the time of crystallization of the vein.

Fig. 4. Concordia diagram for: (a) amphibolite (II); (b) quartz metasomatite (III); (c) aplite (A1 – A5) and pegmatite (I1 – I15)

Conclusions

The outcrops contain the most ancient rocks of the area, i.e., the garnet-biotite and biotite gneisses with the age of metamorphism 2.8 Ga and granodiorites with crystallization age 2722±9 Ma [6]; the pegmatites and plagiogranitoids formed within the gneisses during the
second deformation stage have the ages of 2620±16 and 2636±41 Ma, correspondingly, marking the final stage of Archean evolution in the area; the metagabbroids have a crystallization age of 2587±5 Ma, and are currently represented by metamorphosed and boudinaged bodies of amphibolites, with a metamorphism age of 2507±7 Ma; the quartz metasomatites formed during the stage of gabbroid metamorphosis and deformations have ages of 2522±53 Ma and 2503±67 Ma.

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Viséan Sequence Features from Well Data, Eastern Slope of Melekess Depression, Russia

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Abstract

This study discusses sequence stratigraphy of the Visean succession from well log data for a typical well section of the eastern slope of the Melekess Depression, Volga-Ural Province, Russia. The Viséan deposits overlie the Tournaian deposits with unconformity. These stages, with the Serpukhovian stage, compose the Mississippian Series. The basal Viséan beds are terrestrial and nearshore marine sandstone and mudstone, which represent the initial transgressive sediments of the depositional cycle. These sediments fill the Kamsko-Kinel troughs and the irregularities of the underlying channeled and karstified erosional surface on the Tournaian carbonate beds. The Viséan clastic beds grade upward to marine carbonate and shale units and finally to widespread fossiliferous marine carbonate beds of Serpukhovian and Bashkirian age. The middle Viséan section contains several marine sandstone intervals, indicative of minor cyclic shoreline fluctuations, but overall the Viséan changes upward to mainly carbonate beds. The sequence-stratigraphic composition of the province typical Lower Viséan section is characterized by the presence of sequences, each represented by clastic alluvial, lake and nearshore facies in either the Bobrikian Horizon or the Tulian Horizon.

Generally, the sequences correspond to the Kansas incised valley fill model. Sequences formation was characterized by decreasing frequency and amplitude of the sea-level change upward and transition from a high to a moderate rate of subsidence where only the lowermost part of the transgressive system tract (TST) is preserved.

Keywords: Viséan succession, incised valley, Volga-Ural province

Introduction

More than 200 fields from Viséan oil sandstone and siltstone reservoirs distributed across the entire Volga-Ural province, including the eastern slope of Melekess depression. Oil-productive intervals were mainly found in the Bobrikian horizon and the Tulian horizon of the lower Viséan succession.

The Viséan clastic reservoirs in general are lenticular, discontinuous elongate quartz sandstone bodies of highly variable thickness and extent. Many of them are sinuous channel sandstones, particularly well developed within the Kamsko-Kinel trough areas, which contain many of the oil fields producing from these beds. The thicker sands tend to be more wide spread, except for some of the basal channel sandstones, which occur in deep erosion cuts or incised valleys in the underlying Domanik facies beds and Tournaian carbonates. Porosity and permeability characteristics are highly variable, ranging from very low in siltstone reservoirs to as much as 25-30 percent and 4-5 darcies in coarser sandstones.

The beginning of the Viséan age was marked by a new cycle of sedimentation after prolonged denudation of Tournaian limestones. Such cycles are effectively processed by using a sequence stratigraphy application.
On contour maps, erosion cuts or incised valleys are distinguished as circular to oval shaped, narrow channel forms of small sizes (0.2-5 km) within a denuded surface of Tournaisian carbonate rocks. The distribution of incised valleys often relates to faults, reefs and fractured zones of local uplifts [1].

The Viséan stage overlies the Tournaisian stage. These stages, with the Serpukhovian stage, compose the Lower Carboniferous Series. The Visean stage consists, up the section, of the Radaevkian, Bobrikian, Tulian, Aleksinian, Mikhailovian and Venevian horizons.

The Viséan stage is a lower stratigraphic unit of the Second Paleozoic cycle. This cycle comprised a 50 m to about 800 m sequence of terrigenous clastic sediments of early and middle Viséan age, followed by fossiliferous marine carbonates of late Viséan, Serpukhovian and Bashkirian ages.

The basal Viséan beds are continental and nearshore marine sandstone and shale, which represent the initial transgressive sediments of the depositional cycle. These sediments fill the Kamsko-Kinel troughs and the irregularities of the underlying channeled and karstified erosion surface on the Tournaisian carbonate beds.

The Viséan clastic beds grade upward to marine carbonate and shale units and finally to widespread fossiliferous marine carbonate beds of Serpukhovian and Bashkirian age that covered the entire platform [2].

General emergence of the Russian Platform occurred following deposition of the Tournaisian reef and other carbonate facies. This was associated with weathering, leaching, and probably partial dolomitization of the underlying carbonates. Karst dissolution features are reported at places in the upper Tournaisian section, and deep channeling of underlying beds by early Viséan stream systems is reported in the Kamsko-Kinel troughs and adjacent heights.

Deposition of the Viséan clastic sediments essentially completed the filling of the Kamsko-Kinel troughs. After the Viséan time, no evidence of the Kamsko-Kinel trough system is found [3]. The middle Viséan section contains several marine sandstone intervals, indicative of minor cyclic shoreline fluctuations, but overall the Viséan changes upward to mainly carbonate beds.

The major source area for the Viséan clastics was the Baltic Shield to the northwest; a second less important source was in the vicinity of the Voronezh crystalline massif [2]. Some interbedded gypsiferous strata are present in the Buzuluk depression. Coal deposits are present in the coastal plain and shallow marine facies that filled the Kamsko-Kinel troughs and also along the north and east borders of the Voronezh high.

The Bobrikian Horizon overlies the Tournaisian stage with unconformity and rarely conformably the Radaevkian Horizon. The Bobrikian horizon spreads widely. It is composed of sandstones, siltstones, mudstones, coals and rarely redeposited limestones. Sandstones are gray or dark-gray, quartz, fine to coarse-grained, oil-prone, interbedded with siltstones. They are thin, subhorizontally layered, with plant detritus. Mudstones are dark-gray, with coal.

The upper boundary of the Bobrikian Horizon is marked based on mudstones with the Tulian spore and pollen assemblage.

The Tulian Horizon spreads widely. The upper boundary of the Horizon is defined by carbonate rocks with Aleksinian foraminifers. The horizon consists of mudstones and sandstones with thin interlayers of limestone.

In present work the sequence stratigraphic frame was built for the Tournaisian-Viséan succession based on well log data from a typical well section of the eastern slope of the Melekeess Depression.

**Methods and Results**

In well sections, sequence-stratigraphic framing is processing based on log and core data in a stratigraphic context (e.g., [4]).
Classification of geophysical log signatures and their interpretation in terms of facies analysis is considered as one of the tools to obtain a sequence-stratigraphic frame (e.g., [5]).

Well section can be presented in sequence-stratigraphic composition by the following procedures:

- identification of sequence-stratigraphic internal and external surfaces;
- interpretation of vertical sequence and parasequence composition.

SB (sequence boundary), mfs (maximum flooding surface), TS (transgressive surface) are found in either clastic, or carbonate systems. In many cases SB is based on coarse sandstone overlaid eroded surface of underlying depositions of HST (high stand system tract) of the previous sequence. These coarse sediments started the filling of erosion cuts and incised valleys.

The section from the incised valley is characterized by specific signatures of system tracts (e.g., [5], [6]). The low stand system tract (LST) is composed of braided river sediments with low values of gamma-ray (GR) intensity, coarse grain aggradation signature. Transgressive system tract (TST) consists of meandered river sediments (bell shape signatures). TS is marked by peak of resistivity. Greatest value of GR intensity signs mfs and transition from TST to high stand system tract (HST), composing of sediments of floodplain and swamp environments.

In a given well (Fig. 1), sequence-stratigraphic composition of the Lower Visean section is characterized by the following features. The lower SB is due to erosion processes on Tournaisian carbonates. The overlying succession is represented by clastic alluvial-lake and river-nearshore sequences in either the Bobrikian horizon or the Tulian horizon.

Similar vertical regularity was observed in an adjacent area (e.g., [6]) and can be considered as a typical incised valley section in the Volga-Ural province.

![Diagram](image_url)

**Fig. 1.** Typical Viséan incised valley well section, eastern slope of the Melekess Depression. Legend: 1 – sandstone: highly oil-saturated; 2 – sandstone: low oil-saturated; 3 – the alternation of muddy sandstones, siltstones and mudstones; 4 – alternation of siltstones and muddy sandstones; 5 – limestone: oil-saturated; 6 – siltstones and mudstones with coal seams
Discussion

Relative sea-level fall forces the sea to regress and rivers to adjust their gradient to the lower base level. Valley incision induced by sea-level fall operates headward. It can affect the river courses far away from the high stand coastline, depending on the stream power, the time available for erosion and the erodibility of the underlying bedrock. Incised valleys on land and on continental shelves are filled with sediment during the subsequent sea-level rise [7], [8].

Many ancient incised valleys provided habitats for the formation of coal. A general model of the filling of such valleys is shown in Fig. 2. This facies model is mainly based on examples from foreland basins with high to moderate sediment supply. During the LST the valley is commonly filled with deposits from braided rivers. With the onset of transgression (initial transgressive surface), the accommodation space for sediment aggradation increases and the gradient of the river decreases. As a result, the bed-load channels of the formerly braided rivers tend to evolve into the medium-gradient mixed-load channel within fine-grained floodplain deposits. Further up section, such systems may be replaced by mud-dominated channel-floodplain conditions. Coal seams developed during this phase of valley filling are normally thin and not very extensive. At the transition to HST, wide areas outside of the valleys are flooded. This is time period in which thick coal deposits can form, either somewhat below or above the mfs. The sedimentary facies of this time interval vary from lakes and swamps to deltaic, estuarine, tidal to shallow-marine conditions. When the relative sea level starts to fall again during the HST, the sediment accommodation space is reduced, channel units become more truncated and form sheet sandstone bodies. Coal seams again become thin and limited in their lateral extent [7].

![Fig. 2. General model for the filling of incised valley (after [7], modified)](image)

In the studied Lower Visean section (Fig. 1) the basal sequence corresponds to the idealized cross-section (Carboniferous valley fills in Kansas), where the valley was cut down to the top of the previous marine limestones (Fig. 3). All the coal seams were formed during transgression.

The major coal seam in Fig. 3 is affected by a second period of valley incision. This phenomenon is common when coal seams occur close to the maximum flooding surface. In these cases, the frequency and amplitude of the eustatic sea-level change was high in comparison to a moderate rate of subsidence, where only the lowermost part of the TST is preserved.
In the studied section (Fig. 1) the lower succession (pink coloured), overlying Tournaisian eroded carbonates, reflects the features described above: coal seams in incised valleys mainly form in the late TST and at the transition from TST to HST. Their full or partial preservation depends on the accommodation space which is left after subsequent sea-level fall causing erosion and cutting.

Middle (orange coloured) and upper (yellow coloured) successions (Fig. 1) can be considered as close to the Kansas model (Fig. 3) cycles of river and lake or sea littoral deposits with no phase of significant coal seam development.

Conclusions

On the eastern slope of the Melekess Depression, the Lower Viséan sedimentary succession (the Bobrikian and the Tulian Horizons) consists of three sequences. Generally, they correspond to the Kansas incised valley fill model. Sequence formation was characterized by decrease of the frequency and amplitude of sea-level change upward and transition from high to moderate rate of subsidence where only the lowermost part of the TST is preserved.

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The Relationship Between the Rate of Microbial Processes and Methane Content in the Bottom Sediments of the Sea of Japan

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Abstract

The interrelation of microbial processes in marine sediments of two areas in the Sea of Japan was studied. The southern area is located in the north of the Central (Japan) Basin; the northern area covers the southern part of the Tatar Trough near the La Pérouse Strait. It is shown that microbial processes are less dependent on each other in the southern area than in the northern area, which allows us to conclude that the carbon source is more diversified in the southern area. In the northern area, the processes of methanotrophy and methanogenesis are more balanced relative to each other than in the southern area. A high correlation between microbial methane oxidation and sulfate reduction is revealed in the northern area. The study was conducted during the expedition of POI FEB RAS on the R/V “Akademik M.A. Lavrentyev” (Cruise № 81, 2018).

Introduction

Marine sediments cover more than two thirds of the Earth’s surface; they are complex systems that are affected by the interaction of geological, hydrological, physicochemical and biological factors [4]. Marine sediments are known to play an important role in the global carbon and nutrient cycles. Carbon is the most important nutrient chemical element that forms the basis of all organic and bio-organic compounds. Marine sediments are generally characterized by the absence of oxygen and so microbial processes will be dominated by the activity of anaerobic bacteria. Carbon turnover in the presence of electron acceptors therefore involves interaction of the carbon, nitrogen and sulfur cycles [2], [5]. Investigation of the methane turnover of microbial processes occurring in bottom sediments is the major issue concerning microbial biogeochemistry in the seas [7].

The aim of this study is to study the correlation between rate of denitrification, sulfate reduction, destruction of C-org, methanotrophy processes and methane content in the bottom sediments of the Sea of Japan.

Material and Methods

The study area covers from 43°30’-46°30’N, and stretches from the coast of Primorye in the west to the border of the Russian economic zone in the east. The area is subdivided into southern: located within the north of Central (Japan) Basin; and Northern, covering the southern part of the Tatar Trough at the margin of the La Pérouse Strait.

The objects of study were sediment samples obtained from the surface sediment of the oxidized layer. Sampling of bottom sediments was carried out in accordance with the requirements [10].
Denitrification measurements used the inhibition acetylene method [3]. Sulfate reduction and destruction of $C_{org}$ were determined by titration [8]. Microbial methane production and consumption was conducted using metabolic inhibitors [9]. Growth experiments with bacteria were conducted using metabolic inhibitors [9]. Methane concentration in the bottom sediments was determined as 13% vol.

All statistical analyses were performed with R ver. 3.1.0 software (R Core Team). Evaluation of the emissions presence carried out using the Dickson test; the compliance of the samples with the normal distribution law was checked using the Shapiro Wilk criterion; significance of the results was determined by the method of univariate analysis of variance using the non-parametric Kruskal Wallis test. Verification of the null hypothesis was carried out by the ANOVA method. To visualize the correlation, we used a corrplot 0.84 package.

Results

In both studied areas of the Sea of Japan, the highest methane concentrations in the bottom sediments were observed at depths from 1400 to 1850 m. At the same time, the average concentration of methane in the bottom sediments of the northern area was higher than in the southern (from 1.8 to 45.4; from 2.2 to 154.1 nM/kg, respectively).

In the study of microbial processes, the rate of methanotrophy and methanogenesis was determined using the chromatographic method. A feature of this method is that it takes into account only the total concentration of methane in the sample, regardless of its origin.

Therefore, if the result is positive – methanotrophy prevails over methanogenesis, and if negative – the methanogenesis is more intense.
In the southern area, analysis of microbial processes was carried out at stations with a water depth of over 700 m. The destruction of \( C_{\text{org}} \) increased slightly with decreasing depth, and the speeds of denitrification and sulfate reduction, on the contrary, decreased. However, the maximum value of these indicators was reached at a depth of 1500 m at three stations.

Methanogenesis prevailed over methanotrophy at stations with a sampling depth from 700 to 2500 m, but with a further increase in depth, on the contrary, methane oxidation exceeded its synthesis (from -1.7 to -88.9; from 0.2 to 239.2 nM/kg per day, respectively).

In the northern area, the depth of sampling varied from 500 to 2000 m. The rate of the \( C_{\text{org}} \) destruction with a decrease in depth varied slightly. The intensity of denitrification increased with increasing depth. At depths from 1500 to 2000 m, the fluctuation of the rate of sulfate reduction did not depend on depth. The rate of destruction of the \( C_{\text{org}} \) in the southern area was higher than in the northern, and denitrification and sulfate reduction was lower. In the northern area, the microbial processes of methanotrophy and methanogenesis are separate from the others and are at a higher hierarchical level than the others. The processes of methanogenesis are leading (from -14.5 to -168.4 nM/kg per day, respectively). At all points of selection, except at one station (LV81-52CG), methanogenesis prevailed over methanotrophy (4.1×10^4 nM/kg per day). In addition, at this point, relatively high rates of sulfate reduction processes were observed.

**Discussion**

In the southern area, microbial processes associated with methane are closely interdependent with \( C_{\text{org}} \) decomposition, bacterial growth, and sulfate reduction. Based on the results of the analysis of variance by ANOVA at the southern test site, the stations can be divided into two groups. In the first, methanogenesis either prevails over methanotrophy, or both processes counterbalance each other; in the second, the rate of methanotrophy is higher than the rate of methanogenesis. The first group also includes stations with a high rate of \( C_{\text{org}} \) decomposition.

In the second, there are stations at which a high gross growth rate of microorganisms is recorded. When analysing the data obtained in the northern area, it was revealed that all stations, except one, are combined into one cluster. Microbial processes associated with methane are leading.

The increase in methane content in bottom sediments suppressed sulfate reduction in the northern area and slightly stimulated it in the southern. In the northern area (polygon), there was a close relationship between the positive relationship between the increase in methane concentration and the participation of bacteria, both in its synthesis and in its oxidation. In the southern polygon, this trend was not observed.

In the northern area, the growth rate of bacteria in bottom sediments depended on methane content, sulfate reduction rate and sampling depth. Moreover, if the first two factors stimulated growth of microorganisms, the increase in depth inhibited the growth of bacteria.
Fig. 2. Correlation coefficients (B) between 1 – sampling depth (m), 2 – methane content in the bottom sediments (nM/kg) and microbial processes (2 – denitrification rate (mgNO$_3$/h), 3 – sulfate reduction rate (mg S/h), 4 – C$_{org}$ decomposition rate (mg O$_2$/l×day)), 5 – balance between methanotrophy and methanogenesis (nM/(l×day)), 6 – gross growth rate of bacteria (h$^{-1}$)).

**Conclusions**

In the southern area, the concentration of methane in bottom sediments is the depth of sampling. Also, in this area there is a weak positive correlation of methane with the rate of sulfate reduction. The remaining microbial processes are relatively independent of each other, which may indicate that methane is not the leading C source in the biogeochemical cycles of the area.

In the northern area, the change in methane concentration had a stronger effect on microbial processes. The closest connection in this area between the growth of bacterioplankton in bottom sediments and the balance between the processes of methanotrophy and methanogenesis were observed. An increase in methane concentration in bottom sediments is combined with high rates of organic matter destruction and suppression of sulfate reduction. As the sampling depth increases, the denitrification rate increases, and a weak negative relationship is observed with the growth of bacteria. In the bottom sediments of the northern area, the decomposition of C$_{org}$ and sulfate reduction are in insignificant competition relative to each other. Thus, we can conclude that in the northern area methane is an integral part of the biogeochemical cycle and has a significant impact on microbial ecosystems.

Microbial research on the bottom sediments revealed significant differences between biogeochemical processes among the 2 areas in the north of Japan Sea. Both areas have correspondingly different gas-geochemical features, related to prevailing gas genesis and consumption pathways. The northern area sites are affected by the huge methane anomalies (up to 13 % vol.), promising for the search for gashydrate, and the southern area has signs of hydrocarbon seeps in the deepest area of the Sea of Japan.

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REFERENCES

Late Moscovian and Kasimovian Calcareous Algae from the “Malaya Pokayama” Section (Volonga River, North Timan)

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Abstract

A characteristic of the Late Moscovian and Kasimovian calcareous algae assemblages in the “Malaya Pokayama” section in Volonga river (North Timan) is presented. The flora is dominated by chlorophytes and rhodophytes. Most of them are identical with species recorded in the Urals, but there are some differences in their stratigraphic distribution.

Keywords: North Timan, “Malaya Pokayama” section, calcareous algae, Late Moscovian, Kasimovian

Introduction

The most complete Carboniferous successions of North Timan are present in the “Malaya Pokayama” section (Fig. 1). Late Moscovian and Kasimovian carbonate deposits are represented by the interbedding of detrital, organogenous algal limestones, and secondary dolomites. Diverse fossil groups (brachiopods, foraminifera) have been studied from these strata [1], [2], [3], [4]. Calcareous algae in sections of North Timan still remain poorly investigated, in spite of their wide distribution and significant role in the existence of paleo communities. The characteristics of the algae distribution in the “Malaya Pokayama” section is based on the foraminifera zones established earlier [4].

Material and Methods

The section “Malaya Pokayama” was studied earlier by the author under the aspect of foraminifera distribution [4]. Foraminifera complexes were determined from the early Carboniferous to the early Permian (Artinskian stage). The results of the study of algae presented in this article cover the stratigraphic interval from the Late Moscovian to the end of the Kasimovian time. This corresponds to the foraminifera interval from Beedeina elegans Zone to Rausertes quasiarcticus Zone. Remains of calcareous algae in this stratigraphic interval of the “Malaya Pokayama” section were found in more than sixty thin sections.

Results

Two foraminifera zones have been established in the Late Moscovian deposits (Beedeina elegans Zone, Praeobsolletes burkemensis Zone).

In the strata of the Beedeina elegans Zone green algae of the Beresellacea family (Beresella polymorosa Kulik) dominate among the algophlora. There are also less common phylloid algae Eugonophyllum johnsoni Konishi et Wray and rare dasycladaceans Anthracoporella sp. (Fig. 2, 1-4).

Towards the top of the Moscovian strata in North Timan (Praeobsolletes burkemensis Zone) algal bioherms and biostromes are found. Phylloid algae Eugonophyllum johnsoni Konishi et
Wray have a main rock-building role. At the base of organic buildings beresellids are abundant and diverse: *Beresella polyramosa* Kulik, *B. ex gr. ishimica* Kulik, *Dvinella comata* Khvorova, *Donezella lutugini* Maslov, *Uraloporella variabilis* Korde. Dasyclads *Anthracoporella* aff. *vicina* Kochansky et Herak and *Anthracoporella* sp. are rare. For the first time for this section red algae *Ungdarella uralica* Maslov appeared. The tops of organogenic buildups are usually inhabited by frame forming algae *Microodium*, indicating very shallow conditions (Fig. 2, 5-14).

There are three foraminifera Zones are distinguished within Kasimovian stage in the North Timan (*Protriticites pseudomontiparus – Obsoletes obsoletus* Zone, *Montiparus montiparous* Zone, *Rausertes quaiarcticus* Zone).

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Fig. 1. Location and stratigraphic column of the “Malaya Pokayama” section
At the beginning of the Kasimovian (*Protriticites pseudomontiparus – Obsoletes obsoletus* Zone) the association of algoflora have been changed insignificantly. Green algae are dominant (*Beresella polyramosa* Kulik, *Uraloporella variabilis* Korde, *Dvinella comata* Khvorova). Red algae are rare (single *Eflügelia johnsoni* (Flügel), *Archaeolithophyllum* sp. (Fig. 3, 1-6).

Since the *Montiparus montiparus* Zone there has been a qualitative restructuring of the algal assemblages. Beresellids (*Dvinella comata* Khvorova) occur rarely. Red algae are becoming dominant in the communities. They include abundant *Eflügelia johnsoni* (Flügel) and rarer *Ungdarella* sp., *Urtasimella laxa* Tchuvashov et Anfimov, *Solenopora* aff. *russiensis* Maslov, *Parachaetetes* sp. (Fig. 3, 7-12).

In the lower part of the *Rauserites quasiarcticus* Zone the algal assemblage comprises again of beresellids (*Dvinella comata* Khvorova, *D. distorta* Kulik, *Beresella polyramosa* Kulik) and dasyclads (*Anthracoporella* aff. *uralica* Tchuvashov, *Gyroporella* sp.). However, at the uppermost Kasimovian, they are replaced by the microproblomatic algae *Tubiphytes*, which indicates a change in the environmental situation (Fig. 3, 13-16).

**Discussion**

Carboniferous algal flora in the “Malaya Pokayama” section is similar in the taxonomic composition to the Uralian assemblages. However, regional differences in their stratigraphic distribution are observed.
The almost complete disappearance of beresellids, and the appearance of the microproblematic algae *Tubiphites* at the Moscovian-Kasimovian boundary are noted in the Uralian sections [5]. Whereas in the North Timanian sections beresellids continued to play a significant role in algal communities throughout Kasimovian, especially in its beginning. And the genus *Tubiphytes* in the North Timan basin became abundant only at the end of the Kasimovian.

Age intervals of phylloid algae *Eugonophyllum* domination also differ; in the Urals they are confined to the Kasimovian whereas in North Timan they are confined to the Uppermost Moscovian strata.

**Conclusion**

The paleogeographic position of North Timan during the Late Moscovian and Kasimovian identified some differences in the composition of algal flora in comparison with the Urals. The algal communities of North Timan have the greatest similarity with those in the areas distinguished by B. Mamet as the Arctic biogeographic province [6], [7]. Most algae have a wide stratigraphic range. Their spatial and temporal distribution depends on the paleogeographic position and the paleoecological conditions of their habitat regions. Thus, algal flora has only local age significance, but it is very important for paleoecological reconstructions.

**REFERENCES**

Geology and Geochemistry of the Oil and Gas-Bearing Upper Paleozoic Complex of the Labagan Field (Arctic Zone of the Timan-Pechora Province)

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Abstract

The results of additional geochemical studies of biodegraded oil from the Artinskian deposit of the Labagan oil Field showed that the original organic matter of the oils was accumulated in coastal and marine environments, and that the maturity of the oils corresponds to the beginning of the “oil window”.

Keywords: “oil window”, Arctic sector of Russia, Timan-Pechora Province, geology and geochemistry

Introduction

The Labagan oil Field is geographically confined to the Sorokin Swell of the Varandey-Adzva Hydrocarbon Region of the Timan-Pechora Province (TPP), located in the Arctic zone of Russia. It is important to study depleted deposits north of the TPP for further research, and to facilitate the identification of new deposits in the Arctic region of Russia.

The Labagan Field is confined to an anticline of the same name in the Sorokin Swell, in the Varandey-Adzva structural zone of the TPP. Oil deposits belong to the stratigraphic hydrocarbon traps type. Usually, traps are located one above the other and are combined in plan. The reservoir is a secondary fracture porosity reservoir. A succession of the Labagan Field is composed of rocks dating from the Silurian to the Quaternary. At present 15 oil deposits have been discovered in the Labagan Field [1]. We will only present data for the Artinskian (Lower Permian) carbonate deposits.

The Lower Permian is clearly divided into two units: the upper – terrigenous; and the lower – carbonate. In the upper (terrigenous) unit, the Kungurian and the Upper Artinskian are well-established, represented by sandstones, siltstones and shales. This unit conformably overlies the Lower Artinskian carbonate deposits and serves as a cap rock for Artinskian oil reservoir.

The Kungurian deposits predominantly consists of dense, dark gray to black shales with layered silt and black carbonaceous material, which is pyritized, and contains imprints of fossils. The total thickness of the terrigenous unit of the Kungurian and Artinskian is between 163 and 194 m.

The Lower Artinskian, Sakmarian and Asselian unconformably overlie the carbonate succession of the middle Carboniferous. In some boreholes the Upper Carboniferous deposits were discovered [2]. The main productive horizon of the Artinskian is composed of permeable carbonate rocks: fine-grained and bioclastic limestone which is both porous and fractured, and ranges in colour from light gray to dark and brownish gray. Throughout the width of the limestone there are isolated layers of marl. The thickness of the productive horizon varies from 26 to 57 m [3].

Below the reservoir, the succession predominantly consists of fine-grained argillaceous limestones with intercalations of marls and shales. Often, they are marl-like, thinly-layered, and
are fractured in areas. The limestones contain imprints and fragments of fossils, along with inclusions of plant debris and pyrite. The total thickness of the undifferentiated Artinskian-Asselian interval varies from 167 to 202 m.

The Middle Permian is represented only by the Ufimian Stage which is established conditionally. Based on core materials from wells 74, 75, 82 and 141, Ufimian strata are represented by alternations of terrigenous rocks, consisting of continental, lagoon-marine, and lagoon freshwater facies, with single layers of dense light gray limestone. The thickness of these strata can be up to 236 m.

The Artinskian oil deposit (P_{ar}) is confined to carbonate reservoirs of the porous and fractured porous types. It has dimensions of 12 km by 3.2 km by 97 m and contains viscous, heavy oil (0.941 g/cm^3). The average porosity of the reservoirs is 22%, and the recovery factor is 45%. Properties of the oil were studied by borehole sample, and it was determined that the share of oil on average is 0.936 g/cm^3. The content of tar and asphaltenes is 16.38% and 5.58% respectively. Paraffinic oils were also present (2.7%), and there was a high sulfur content (2.46-2.64%). To determine the type of organic matter that served as the source of oil from the Lower Permian deposits, as well as the conditions for its accumulation and the degree of maturity of the oil, additional geochemical studies were made.

**Methodology**

The asphaltenes of the oils were precipitated from a benzene solution (1 ml/g) of the oils by n-pentane in a ratio of 40 ml/g. The saturated fraction was obtained using column chromatography on silica gel with n-hexane as the eluent [4].

The saturated hydrocarbon biomarkers in the oil fractions were analysed by gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS).

The normal and isoprenoid alkanes of the saturated oil fractions were analysed using gas chromatography (GH) with a Kristall-2000M chromatograph (capillary column DB-5, 30 m × 0.32 mm × 0.25 μm). The temperature was programmed to range from 110 to 300 °C at a heating rate of 5°/min. Hydrogen was used as the carrier gas.

The distribution of steranes and terpanes was analysed by GC-MS. The GC-MS analysis was performed using Shimadzu 2010 Ultra gas chromatography-mass spectrometer (column HP-5, 30 m × 20 mm × 0.25 μm) equipped with a computer data acquisition and processing system, in SIM mode with recording ions at m/z 217 for tetra- steranes and m/z 191 for terpanes gopanes. The temperature was programmed to range from 110 to 300 °C at a heating rate of 5/min. Helium was the carrier gas.

**Results and Discussion**

The analysis of the hydrocarbon fractions of oil from the borehole samples of a number of wells in the Labagan Field from the Artinskian carbonate sediments reveals that their yield varies from 11.79 to 16.45%. The gas-liquid chromatograms of oil samples indicate that there is a large “hump” and an absence of peaks of n-alkanes and isoprenanes, which is typical of biodegraded oils (Fig. 1).

The presence of sterane and terpane hydrocarbons was established by chromatography-mass spectrometry in all the oil samples studied (Fig. 2). The distribution of steranes of composition C27: C28: C29 is almost identical. In all oils there is a slight predominance of ethyl cholestane (C29, 48%). The content of cholestane (C27) is 21-23%.
Triterpane hydrocarbons are represented by hopanes from H27 to H35. The distribution of hopanes of C31-C35 composition – the homohopane index (C35/C31+C35) – is used by petroleum geologists as an indicator of the sedimentation conditions of the original OM [5], [6], [7]. Low values of this parameter (0.14-0.15) indicate the existence of redox conditions in sedimentation of the initial OM in early diagenesis.

To determine the degree of the maturity of the OM, the relationship between the initial biological steranes (configuration ααα20R) of C29 composition and isosteranes that have been newly formed as a result of catagenetic processes (αββ 20R + 20S) [8] (coefficient 20S/20S+20R – 0.45-0.46) is often used; as is the ratio of geosteranes – 5α(H)14β(H)17β(H) – to biosteranes – 5α(H)14α(H)17α(H) – which is written as αββ/ααα + αββ [7] (0.56-0.45); as well as the relative content of moretane (6.65–8.08); the ratio of neohopane C27 (Ts) to the regular hopane C27 (Tm) (0.47-0.48); and the coefficient 22S/22S+22R for homohopane C31 [9], [10] (0.53-0.54).

Based on the values of these coefficients, it can be said that the maturity of the oils corresponds to the beginning of the “oil window”.

Fig. 1. Typical chromatograms of oils from Permian deposits
Fig. 2. Typical mass fragments of oils from Permian deposits (m/z = 217 are steranes, m/z = 191 are terpanes)

Conclusions

Thus, we can conclude that the original organic matter of the oils was accumulated in coastal and marine environments, and that the maturity of the oils corresponds to the beginning of the “oil window”. However, to clarify data on the genesis of oil, additional research, such as the thermolysis of asphaltenes is needed.

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REFERENCES

The Lower Permian Marine Succession of Pay-Khoy: Correlations and Problems in Stratigraphy

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Abstract

This article discusses the stratigraphy of the Lower Permian marine terrigenous successions of two tectonic structures of Pay-Khoy – Kara Depression (North-eastern Pay-Khoy) and Korotaikha Depression (Southwestern Pay-Khoy). Since the Artinskian, these different regions were characterized by deep-water terrigenous sedimentation with proximal facies in the North-East (Tarkhanayakha and Satose Members) and distal in the South-West (lower and upper sub-formations of the Gusinaya Formation). We propose a new correlation scheme for the marine Lower Permian deposits of these areas, using known ammonoid records and the changes in sedimentary environments.

Keywords: Lower Permian, terrigenous deposits, correlation, Kara depression, Pay-Khoy

Introduction

A significant contribution to the stratigraphy of the Permian deposits of Pay-Khoy was made by A.A. Chernov, K.G. Voynovskiy-Kriger, A.V. Makedonov, V.N. Shmelev, V.I. Ustritsky, A.S. Miklyaev, F.I. Entsova, V.A. Guskov, S.K. Pukhonto and others. The stratigraphic scheme of the Permian deposits in the southwestern Pay-Khoy was developed in the last century. The Lower Permian marine terrigenous sediments are divided here (from bed to the top) to the Gusinaya Fm (P₁gs), Bel’kovskaya Fm (P₁bl) and Talata Fm (P₁tl), and conformably overlie the clayish-carbonate Sezym Fm of the Asselian-Sakmarian age. Such a differentiation of the Lower Permian marine terrigenous deposits is accepted for the whole Pechora Coal Basin.

In recent years, from 2008 to 2016, geological survey work on the State Geological Map (1:200 000) was made in the Northeastern Pay-Khoy, covering a significant part of the Kara depression, the Pay-Khoy uplift and the Baidarata Zone of the Polar Urals [1] and [2]. New geological data were obtained relating to the stratigraphy of the Lower Permian. On the territory of the Kara Depression, new stratigraphic units – Tarkhanayakha and Satose Members (Mb) – were established [1]. The Lower Permian terrigenous deposits of the Kara Depression are divided into the Petarkayakha Formation (P₁pt), Tarkhanayakha Mb (P₁tr), Satose Mb (P₁st) and Liur’yraga Formation (P₁liur). This succession overlies the deep-sea carbonaceous and siliceous shales, silicites, clastic and pelitomorphic limestones of the Karasilova Formation (Fm) (C₂,P,krś) of the Middle Carboniferous to Early Permian (Asselian) age [3]. Thus, there are two separate stratigraphic schemes of the Permian of Pay-Khoy. The first scheme is used for the Southwestern Pay-Khoy and the second is used for Northeastern Pay-Khoy. Both regions are similar in stratigraphic composition and sedimentary environments. The aim of this work is to compare the stratigraphic units of these different regions.
Geological Setting

The Paleozoic Pay-Khoy succession belongs to three structural-formation complexes: two pre-orogenic (shelf carbonate complex and bathyal shale complex) and one orogenic terrigenous [4], [5].

According to Ustritsky [6], the Pay-Khoy pre-orogenic complexes, similar to the western slope of the Polar Urals, form two structural-formational zones (or large facial belts): 1) carbonate Elets facial belt in the southwest and 2) shale (carbonate-silica-shale) Lemva facial belt in the northeast. The sediments of Elets facial belt were formed on a shallow marine shelf.

The sediments of Lemva facial belt were formed in the bathyal conditions of the continental slope on the passive margin of the continent of Euroamerica [7]. The Permian terrigenous sediments on Pay-Khoy form the third complex. It consists of greywacke sandstones, siltstones, mudstones, and includes gravelites, conglomerates, and coals in the upper part. This thick (several thousand meters), mostly clastic complex was formed as a result of the destruction of the collision orogen, located probably in the area of the modern Kara Sea. The sedimentation of clastic material initially occurred in a deep-sea environment (flysch), then continued in a shallow-sea environment (lower molasses) and ended with the formation of an upper continental molasse [4]. These sedimentary environments changed in space and time. In modern terms, the Permian Pay-Khoy terrigenous sediments are widespread in two large tectonic structures – Korotaikha (southwestern Pay-Khoy) and Kara (northeastern Pay-Khoy) depressions, separated by the Pay-Khoy Ridge. It should be stressed that the Pay-Khoy orogenic complex (both in the southwest and northeast) consists of the flysch and molasse, whereas the Polar Ural orogenic complex (on the western slope of the Urals) includes only a part of the flysch which has been preserved from erosion. Therefore, the geological record of Pay-Khoy most fully reflects the history of the orogenic phase of this region.

Results

With the exception of the Petarkayakha Fm of the Sakmarian, conodonts and fusulinids have not yet been found in the Lower Permian terrigenous sediments of Pay-Khoy. The Kungurian age of the Liur’yraga Fm in the northeast of Pay-Khoy has been reliably established based on the finds of Tumaroceras [8], [9]. Other formations are characterized by the Artinskian ammonoids of the genera Artinskaia, Waagenina, Paragastrioceras, and Uraloceras; the species composition does not allow the age to be established more precisely [8]. The correlation of formations of different regions is usually achieved using only lithological features. With the establishment of the Satose Mb, the problem of its correlation arises. Previously, different researchers correlated the Satose Mb with the Bel’kovskaya Fm [10] or Kechpel’ Fm [3], [5], [11]. Modern stratigraphic schemes of Pay-Khoy terrigenous sediments, in which the Bel’kovskaya Fm is correlated with the Satose Mb [1], [9], [12], contradict the history of sedimentation in this basin. Siltstones and mudstones of the Bel’kovskaya Fm (thickness 450-800 m) of the Korotaikha and Kosyu-Rogovskaya depressions form thin layers (0.5-2 cm thick) with gradual transitions and often with bioturbation. Sandstones are not typical for the Bel’kovskaya Fm. These deposits are established as coastal and are considered as part of the lower molasse or schlier [13].

The Satose Mb was studied by the authors on the right bank of the Kara River, eastward of the Kara Astrobleme. This Member is composed mainly of three rock series that follow each other in the section: (1) siltstones and mudstones with a fine-cyclite fabric with landslide intervals, (2) thick sandstones with the gravelites and muddy debrite, and (3) fine-cyclite sandstones, siltstones and mudstones.
The first series reaches a maximum thickness of 95 m. It contained *Uraloceras involutum* (identified by K. Borisenkov). Small slumps of siltstone-mudstones beds form slumping intervals (0.5–25 m thick). Inclusions of lenticular blocks of sandstones and re-deposited carbonate nodules are often recognized, whereas blocks of bioclastic limestones are rare. The latter contain the remains of the brachiopod *Spirifirella* (possibly Artinskian) (identified by G.V. Kotlyar), bivalves, bryozoans, and crinoids. Thin cyclites – a few centimeters of thickness – are characterized by C, D, E layers and D, E layers of the Bouma sequence. Intervals of siltstones and shales without gradational sorting, similar in structure to the Bel’kovskaya Formation, are also widespread in this series. The nature of the sediments of the first series is comparable with the inter-channel sections of submarine channel fans near the basin slope, from where the slumping occasionally transported limestone blocks (olistolites).

The second series is represented by sandstone packages 5-20 m thick with separate beds of massive sandstones up to 3.5 m thick. Gravelites, coarse-grained sandstones and sometimes muddy debrite (up to 5 m thick) are found in this series. These deposits can be interpreted as upper-fan channel sediments.

The third series includes sandstone, siltstone and mudstone beds with clearly visible fine-grained turbidite structures. Some of them are intensively bioturbated. These sediments could be formed on the levee.

The sedimentary environment of the Satose Mb (total thickness 600-1000 m) is closest to that of the upper fan. Therefore, these deposits should not be compared with the shallow deposits of the Bel’kovskaya Fm, but with the upper shale-sandstone part of the Gusinaya Fm of the Korotakhka Depression, which is similar to classical turbidites of the middle and lower parts of the submarine fan. A new stratigraphic correlation of the Lower Permian marine formations of Pay-Khoy is shown in Fig. 1. The scheme of the Early Permian sedimentation is shown in Fig. 2.

Fig. 1. The correlation of the Lower Permian marint deposits of Pay-Khoy.
### Discussion

The terrigenous sedimentation in Pay-Khoy began with the appearance of the Petarkayakha Fm in the Kara Depression, which in the Sakmarian was a residual oceanic basin. The formation (about 300 m) is composed exclusively of siltstones and mudstones with C, D, E layers and D, E layers of the Bouma sequence. Deposits are interpreted as distal turbidites and background pelagic sediments comparable to the lower fan sediments.

An important point for paleotectonic reconstruction is the origin of a foredeep basin above the shelf sediments in the Artinskian time and the continued existence of a residual ocean basin at the same time. Since that time, deep-water terrigenous sedimentation on Pay-Khoy occurs already in a single sedimentation basin with proximal facies in the northeast (Tarkhanayakha and Satose Mbs) and distal in the southwest (lower and upper sub-formations of the Gusinaya Fm). Measurements of oriented structures at the base of sandstones (predominantly of the Tarkhanayakha Mb) indicate the structures, south, and southeast directions of paleocurrents [14]. The Kungurian age was the time of shallow-water sedimentary environments of the lower molasse.

For a long time, owing to the similar lithology, the stratigraphic units of the Korotaikha and Kosyu-Rogovskaya Depressions had been used for the Permian succession of the northeast Pay-Khoy, i.e., for the Kara Depression which is a structure of the foredeep basin [4], [5], [6].

Because the foredeep basin originates only on the shallow shelf basement, and the bathyal sediments serve as the basement of the residual ocean basin, it is highly contentious whether the Permian terrigenous sediments of the Kara Depression can be attributed to the foredeep basin.

---

#### Fig. 2. Sedimentary and depositional environments in the Early Permian basin of Pay-Khoy

<table>
<thead>
<tr>
<th>Stage</th>
<th>Korotayukha Depression</th>
<th>Kara Depression</th>
<th>Collision Orogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kungurian</td>
<td>Beîkorskaya Fm</td>
<td>Lower part of the Liuri’raga Fm</td>
<td>Sea level</td>
</tr>
<tr>
<td>Artinskian</td>
<td>Upper part of the Gusinaya Fm</td>
<td>Satose Mb</td>
<td>Sea level</td>
</tr>
<tr>
<td>Sakmarian</td>
<td>Sezym Fm</td>
<td>Lower part of the Gusinaya Fm</td>
<td>Tarkhanayakha Mb</td>
</tr>
</tbody>
</table>

**Legend**

- sandstone; siltstone, mudstone:
- clayish-carbonate;
- channel;
- slump;

Transport direction: a) from the Orogen; 6) from the side of the Yelets zone.
basin. It is more logical to consider them as part of the West Ural megazone. It was previously established that flysch sediments first filled the residual oceanic basin (or trough) within the Lemva structural-formation zone, and then deep-sea terrigenous sedimentation moved to the territory of the former shallow-water carbonate shelf (Elets structural-formation zone) [15]. The structure of the marine Lower Permian succession and the direction of the paleocurrents indicate simultaneous deep-water sedimentation in the Artinskian over the whole territory of Pay-Khoy. It should be emphasized that similar depositional settings in its southwestern part of the basin appeared later compared to its north-eastern part.

Conclusions

The age of the boundaries and the stratigraphic composition of the Lower Permian marine terrigenous successions of Pay-Khoy can be clarified by further study, but their correlation must consider the direction of the removal of clastic material, and the change in the sedimentary environment in space and time.

REFERENCES

Upper Permian Non-Marine Bivalves *Palaeomutela* Amalitzky, 1892 and *Kidodia* Cox, 1936 from South Africa: First Microstructural Data

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Abstract

The microstructural features of non-marine bivalve genera *Palaeomutela* Amalitzky, 1892 and *Kidodia* Cox, 1936 from the Upper Permian deposits of South Africa are described for the first time. The shells of both genera are characterized by the replacement of primary aragonite by pelitic calcite. This replacement does not completely destroy or change microstructural features of the shells. The shells of *Palaeomutela* contain an outer layer (30-50 μm thick) with simple vertical prisms (simple prismatic: SP) and the main inner layers with the crossed lamellar (CL) structure. The shells of *Kidodia* contain two layers, one complex crossed-lamellar and the other one with radial irregular fibrous prismatic structure. The microstructural features of *Kidodia* exclude this genus from the family Opokiellidae.

Keywords: non-marine bivalves, Permian, South Africa

Introduction

Vladimir P. Amalitzky studied the collections of non-marine bivalves in the Natural History Museum (London, United Kingdom) at the beginning of 1890s. He noted the similarity of the non-marine bivalve fauna from Permian deposits of Russia and South Africa. In 1895, he published a brief comparative analysis of the Permian non-marine bivalves from Russia and South Africa and described the new genus *Palaeanodonta* [1], [2].

Mikhail A. Plotnikov in 1949 also noted the external similarity of some species of the non-marine bivalve genera *Opokiella* Plotnikov, 1949 and *Palaeanodonta* Amalitzky, 1895 from the northern part of European Russia with the oval-triangular shells of “*Carbonicola*” *carinata* Cox, 1936 described from the Upper Permian (Ruhembe Beds, Beaufort series) of South Africa [4]. Later, Alexey K. Gusev [5] also stressed that the genus *Opokiella* have external features similar to the non-marine bivalves described by L.O. Cox [4] under the name of “*Carbonicola*” (“C.” *kidodiensis* Cox, “C.” *carinata* Cox). Also, he pointed out the similarity of *Opokiella pakhthusovae* Gusev, 1990 with the Late Permian genus *Kidodia* Cox, 1936 from South Africa [5, p. 198]. The suggestions of Mikhail A. Plotnikov [3] and Alexey K. Gusev [5] about the similarity of *Opokiella*, “*Carbonicola*” and *Kidodia* from South Africa are based only on the study of the external features of South African bivalves according to descriptions and illustrations in the scientific publications.

Material and Methodology

The study is based on the collections of non-marine bivalves from the Upper Permian deposits of South Africa, which are housed in the Natural History Museum (London, United Kingdom). These are the collection of D. Sharpe [6] studied by Vladimir Amalitzky [1], [2] and
the collection of L. Cox (1936). The authors studied these collections in 2015 thanks to Svetlana V. Nikolaeva.

The studies on the collections of non-marine bivalves have been conducted using a complex of external, internal and microstructural features of the shells [7], [8], [9]. Microstructural features were examined using scanning electron microscopes at the Laboratory of Instrumental Analytics of the Borissiak Paleontological Institute of the Russian Academy of Sciences, Moscow (PIN RAS).

Results and Discussion

Comparison of Palaeomutela from the Permian deposits of the East European Platform with conspecific specimens from the Graaf Reinet locality (Karoo Series, South Africa), housed in the Museum of Natural History (London, United Kingdom) shows a very close similarity in the external features of their shells (Fig. 1, Plate 1).

Palaeomutela (Palaeomutela) keyserlingi Amalitzky, 1892 from the Permian deposits of the East European platform also has similar external shell features (with small variations in the shape of the valves) to the specimens from the Diamond Mines locality (South Africa, in the vicinity of Kimberley; lower part of the Karoo Series, base of the Beaufort Beds).

Vladimir P. Amalitzky [2] identified these specimens as Palaeomutela aff. golowkinskiana Amalitzky, 1892, Palaeomutela aff. orthodonta Amalitzky, 1892, Palaeomutela trigonalis Amalitzky, 1892 [2, Pl. XII, Fig. 7, Pl. XII, Fig. 5, Pl. XII, Fig. 6].

Fig. 1. Palaeomutela (Palaeomutela) fischeri (Amalitzky, 1892), sample 36/13SuA1-12 (Geological Museum of the Kazan Federal University); 1a – mold of the right valve with partially preserved shell; 1b – left valve; 1c – top view, bottom view of the left valve, the ligament is visible; 1d – top view, dorsal view of the left valve, the ligament is visible. Abbreviations: L – ligament, u – umbo.

Locality: Russia, Dvina-Mezen Basin, Aristovo Outcrop

Studying the microstructure of Palaeomutela shells from South Africa for the first time confirmed the presence of the crossed lamellar microstructure, characteristic for this genus.

The primary shell material of the South African Palaeomutela, as of the shells from the Permian deposits of the East European Platform, is replaced by pelitic calcite. We can observe the relicts of first-order lamellae on the splits of the shells (Fig. 2a, c). The first-order lamellae vary in orientation, thickness (30-100 μm thick) and are composed by the lamellae of second order (1-3 μm thick) (Fig. 2c). Generally, the shells of the South African Palaeomutela contain an outer layer (30-50 μm thick) with simple vertical prisms (simple prismatic: SP) and the main inner layers (600-900 μm thick) with crossed-lamellar (CL) structure.
Shells of *Kidodia* Cox, 1936 from the Upper Permian of South Africa (Ruhembe Beds, Beaufort Series) contain two layers with different types of microstructure: the umbo area of the shell is characterized by a complex crossed-lamellar microstructure (Fig. 3) and the central part of the shell consists of irregular fibrous radial prisms (Fig. 4). The interrelationship of these layers needs further research.

![Plate 1](image)

1. **Fig. 1.** *Palaeomutela (Palaeomutela) keyserlingi* Amalitzky, 1892, sample 11209 (Natural History Museum (London, United Kingdom)) [2; Pl. XII, fig. 4]; 1a – general view; 1b – right valve; 1c – left valve; 1d – left valve, photographed at another angle than in Fig. 1c, the ligament is visible. Designations: l – ligament, r – umbo.

2. **Fig. 2.** *Palaeomutela (Palaeomutela) semilunulata* Amalitzky, 1892, sample 11211 (Natural History Museum (London, United Kingdom)) [2; Pl. XII, fig. 10 a-d]; 2a – general view; 2b – partially preserved left valves.

3. **Fig. 3.** *Palaeomutela (Palaeomutela) semilunulata* Amalitzky, 1892, sample 11213 (Natural History Museum (London, United Kingdom)) [2; Pl. XII, fig. 10 a-d]; 2a – general view; 2b – top view; 3b – hinge plate.

Locality: South Africa, Graaf Reinet. Scale bar 0.5 cm.
Fig. 2. Details of microstructure of *Palaeomutela* sp., sample L9534m (Natural History Museum (London, United Kingdom)), a – general view of the upper and inner layers; b–c – preserved fragments of lamellae of first and second order.

*Locus of* South Africa, *Diamond Mines at Kimberly*

Fig. 3. Complex crossed-lamellar microstructure of the *Kidodia stockley* Cox, sample L62984-1 (Natural History Museum (London, United Kingdom)) [4].

*Locus*: Tanganyika, *Ruhembe Beds, Beaufort Series*
According to preserved microstructural features, the genus Kidodia and specimens described by L.O. Cox [4] under the name “Carbonicola”, most likely, constitute a single taxonomic group.

New microstructural data on Kidodia Cox, 1936 as well as its hinge features consisting of 1-2 lateral teeth (Fig. 5) indicate a significant phylogenetic difference from the genus Opokiella Plotnikov, 1949. The point of view [10] that Opokiellidae Kanev, 1983 includes Kidodia Cox, 1936 is erroneous. For the present, the systematic position of South African Kidodia and “Carbonicola” remains uncertain. Most likely these genera are endemic.

Fig. 4. Kidodia stockley Cox, sample L62984 (Natural History Museum (London, United Kingdom)) [4]; a-b – details of the radial irregular fibrous prismatic microstructure of the inner (?) layer of the shell.

Locality: Tanganyika, Ruhembe Beds, Beaufort Series

Fig. 5. Kidodia stockley Cox, sample L62954 (Natural History Museum (London, United Kingdom)) [4]; tooth plate imprint. Designations: u – umbo, tpi – tooth plate imprint.

Locality: Tanganyika, Ruhembe Beds, Beaufort Series

Conclusions

For the first time, microstructural features of the Upper Permian Palaeomutela from the East European Platform and South Africa are described; the similarity of the structure of their hinge is confirmed.

The shell microstructure of Kidodia Cox, 1936 and “Carbonicola” from the Upper Permian of South Africa is studied by the first time. The comparison of microstructural features of these genera does not confirm their phylogenetic affinity with Opokiella Plotnikov, 1949. According
to hinge and microstructural features, the genus *Kidodia* Cox, 1936 should be excluded from the Opokiellidae Kanev, 1983.

**Acknowledgments**

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**REFERENCES**

Gold Bearing Black Shales of the Kamensk Structure
(Chelyabinsk Graben, South Urals)

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Abstract

This article briefly discusses the geological features of the Kamensk structure, located on the eastern slope of the Southern Urals in the Alapaevsk-Chelyabinsk deep fault zone, a complex structure of alternating grabens and horsts composed of volcanogenic-sedimentary rocks of Devonian and Carboniferous ages. Particular attention is paid to the description of the Birgilda carbonaceous shales, which are well-represented here. It was shown that they belong to the low-carbonaceous type and on the standard petrochemical diagrams, this carbonaceous deposit fall into the fields of terrigenous-carbonaceous and carbonate-carbonaceous formations, which, together with the presence of carbonates in the geological section, indicate their formation in the shallow and coastal-shallow-water depositional settings. It has been established that in the black shale formations of the Kamensk structure, gold is confined to intensely dislocated, silicified and sulfurized rocks. The testing of core holes showed gold contents of up to 4.6 g/t and silver up to 11 g/t, which would enable the discovery of a new gold ore deposit.

Keywords: Southern Urals, Kamensk structure, black shales, Birgilda Series, gold, silver

Introduction

Clay-carbonaceous deposits represent a very favorable geochemical environment for the primary chemogenic sorption of gold, molybdenum, tungsten, vanadium, manganese, platinum and other elements [1], [2], [3], [4], [5]. According to a sedimentary-hydrothermal-metamorphogenic model of the formation of gold ore deposits in carbonaceous shales, which is being developed by a number of scientists, it is believed that in areas of magmatism, tectonic activity, and regional and contact metamorphism, gold is mobilized and removed from the amphibolite facies zone and concentrates within the green-shale and epidote-amphibolite facies zones [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18]. At the same time, gold ore mineralization is clearly confined to black-shale formations, which experienced intense tectonic deformation, expressed in silicification, sulfidization and crushing of rocks. These are the geological settings within the South Urals where a number of objects have recently been identified. These objects require attention and evaluation of gold mineralization present [2], [19], [20], [21].

Moreover, black shales are very informative rocks that allow the paleogeographic, physical and chemical conditions of their accumulation, and sources and the direction of drift of terrigenous and volcanic material to be reconstructed [22], [23], [24].

The authors of this study, while collecting the data presented, were directly involved in prospecting, exploration and geological mapping on a scale of 1:50 000 (department of the ChGEE PGO «Uralgeologiya», E.P. Shchulkin et al., 1980-1986), and also a scale of 1:200
000, new series (maps N-41-XIII Plast-2012 and N-41-XIV Troitsk-2016, B.A. Puzhakov et al.).

**Geological Setting**

The Kamensk structure is part of the Alapaevsk-Chelyabinsk deep fault zone. It is bounded from the west and east by the Chelyabinsk-Suunduk and Krasnogvardeisk anticlinoria and represents the checkboard structure of alternating grabens and horsts composed of volcanogenic-sedimentary rocks of Devonian and Carboniferous ages (Fig. 1).

![Geological map of the Kamensk structure](image)

**Fig. 1.** Geological map of the Kamensk structure (compiled using materials from Shchulkin E.P.). Legend: 1 – sandstones, 2 – conglomerates, 3 – limestones, 4 – carbonaceous schists, 5 – basalts, 6 – andesites and their tuffs, 7 – plagiogranites, 8 – diorites, quartz diorites, 9 – significant gold contents, 10 – conodont points finds, 11 – foraminifera find points, 12 – area favorable for detecting alluvial gold, 13 – geological section line (see Fig. 2), 14 – contour of the Kamensk structure prospective for the discovery of gold mineralization.

The geological structure of the area considered is represented by: Kosobrodka (D_2ks) (tuffs of andesibasalts, dacites and rhyodacites), Tugunda, Birgilda and Ukhanovka (C_2uh) (sandstones, conglomerates) Series, with intrusive bodies of the Birgilda-Tomino complex. Carbonaceous deposits are only found in the middle two series.
The Tugunda Series (Ctg) is represented by arkose and polymictic sandstones and conglomerates, carbon siltstones and mudstones. The relationship with the underlying rocks is unconformable. The contact with overlying Birgilda Series is conformable. B.A. Puzhakov used the U-Pb (SHRIMP-II) method to perform analysis to determine the zircon age using from granite pebbles as part of conglomerates. The concordant data of 364±6.7 Ma and 361.3±6 Ma obtained correspond to the Upper Devonian-Lower Carboniferous. Therefore, the age of the series cannot be older than the Early Carboniferous.

The Birgilda Series (Cbg) is composed of white and gray bioclastic limestones (close to contacts with typically marbled intrusive massifs) interbedded with carbonaceous, calcareous shales and siltstones, forming independent layers and horizons. The total thickness of the series is approximately 700 meters. (Fig. 1, 2).

![Fig. 2. Geological section along the line A – A1 and the scheme of sampling sediments of the Birgilda Series. Legend: 1 – sandstones, 2 – limestones, 3 – carbonaceous schists, 4 – andesites and their tuffs, 5 – diorites, quartz diorites, 6 – wells, their numbers, depth and sampling interval (see Table 1).](image)

On the standard petrochemical diagrams, its carbonaceous deposits correspond to fields of terrigenous- carbonaceous and carbonate- carbonaceous formations [22]. Thermogravimetric analysis of the least altered carbonaceous deposits outside the zones of intrusive contacts and intensive tectonic deformation showed an average organic carbon content of 0.5 to 2.0%, which allows them to be classified as low-carbonaceous type [24]. Their chemical composition and the nature of the distribution of rare-earth elements is comparable to similar deposits of the Tugunda Series. The alternation of coarse-, medium- and fine-detrital rocks throughout the section reveals a transgressive character, and the presence of carbonates in the section suggests they were formed in shallow and coastal-shallow-water depositional environments.

The Visean-Serpukhovian age of the series is accepted by E.P. Shchulkin based on characteristic fossils. The following foraminifera were collected and identified in light gray siliceous limestones on the left bank if the Ui River (Fig. 1, Nos. 2, 3): *Cornuspira volgensis* (Raus.), *Forschia* sp. indet., *Plectogyra omphalota* var. *minima* (Raus. et Reitl.), *Diplophaerina maljavkini* (Mikh.), *Archaeodiscus* sp. indet., *Arch. cf. pauxillus* Schlyk., *Earlandia vulgaris* minor (Raus.), *Endothyra similis* (Raus. et Reitl.), *Endostaffella asymmetrica* Rosov., *Mediocris breviscula* (Gan.), *Asteroarchaediscus ovoides* Raus; as well as the conodonts (Fig. 1., No. 1): *Streptognathodus nodulifens* Ellison et Gram.

The Birgilda-Tomino complex (δD-Cbt) includes small lenticular massifs embedded among the deposits of the Kosobrodka Series, composed of diorites, quartz diorites, and quartz diorite-porphyrtes. Its boundaries with the host rocks are intrusive, steep and dip under the massif, the host rocks are propylitized. The complex is associated with numerous copper-porphry objects, as well as gold mineralizations in carbonaceous shales [25]. The absolute age of diorites on the map of N-41-VIII, determined by N.S. Kuznetsov in 1999 using the K-Ar...
method, corresponds to the Late Devonian-Early Carboniferous. However, recently obtained data suggest their Silurian age.

**Results and Discussion**

Carbonaceous deposits of the Tugunda and Birgilda Series are known as a favourable environment for the localization of precious metal mineralization. Metamorphogenic gold mineralization are located in a 5×2 km tectonic block, which is a narrow anticlinal fold composed mainly of carbonaceous carbonate-terrigenous deposits. In the course of prospecting and exploration, a large number of deep core wells were drilled, which made it possible to clarify the geological structure of the territory in question and evaluate the ore content of its constituent rocks.

**Gold occurrence No. 1**

High gold contents of up to 3.0 g/t and silver contents of up to 11.0 g/t were obtained by assay in furrow samples (Fig. 1, No. 1). The maximum contents of precious metals are confined to beds of gray and dark gray carbonaceous shales 60 to 150 m thick (Fig. 2, Table 1). These shales contain occasional thin (0.5-6.0 cm) quartz-carbonate veins crossing the foliation and carrying small quantities of pyrite and chalcopyrite (up to 4%).

<table>
<thead>
<tr>
<th>No.</th>
<th>Wells/Intervals (m)</th>
<th>Au, g/t</th>
<th>Ag, g/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>W-4/99.6-103.1</td>
<td>2.0</td>
<td>1.7</td>
</tr>
<tr>
<td>2</td>
<td>W-3/275.9-278.0</td>
<td>3.0</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>W-3/280.0-295.6</td>
<td>0.4</td>
<td>6.2</td>
</tr>
<tr>
<td>4</td>
<td>W-1/56.0-57.0</td>
<td>1.6</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>W-1/84.4-93.2</td>
<td>0.7</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>W-1/101.0-118.0</td>
<td>0.5</td>
<td>11.0</td>
</tr>
<tr>
<td>7</td>
<td>W-1/130.6-135.8</td>
<td>1.3</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: dash-level lower than the sensitivity of the method can detect.

**Gold occurrence No. 2**

In the exocontact zone of porphyry diorites of the Birgilda-Tomino complex, the precious metal content is even higher (Fig. 1, No. 2). Testing of intensely foliated and sulfidized carbonaceous deposits showed Au contents of up to 4.6 g/t. A total geochemical anomaly of arsenic up to 0.02% was observed throughout the carbonaceous shales; spectral analysis revealed increased values of copper – 0.1%, zinc – 0.01% and barium – 0.07%.

**Gold occurrence No. 3**

Mineralization similar to the first occurrence is indicated in the southern part of the area. In the low-carbon gray quartz-chlorite-sericite schists) a meter zone with poor sulfidization (up to 1%) and quartz veins up to 0.3 m thick has been found. According to the assay data, the gold content is 1.6 g/t and the silver 5.0 g/t.

In the course of geological mapping work, we tested Neo-Pleistocene weathering crusts, consisting mainly of yellowish-brown loam and clay with fragments of vein quartz and carbonaceous shales. By washing in a tray, we obtained several small gold grains (according to the classification of N.V. Petrovskaya [26]), which are thin flakes of 0.2×0.4×0.01 mm, as well as isometric grains of medium size of 1x1.5 mm and 0.5x1 mm (weighing 10 and 2 mg, respectively). Judging by the shape of the gold grains, the metal was transported a short distance
from the ore body, which could comprise zones of quartz-sulfide mineralization, as well as the carbonaceous-clay shales of the Birgilda Series.

Conclusions

Thus, the carbonaceous shales of the Birgilda Series are referred to the low-carbonaceous type and treated as terrigenous – carbonaceous and carbon – carbonaceous formations. The presence of stratified intercalations of carbonate-siliceous shales and limestones suggest the formation of the deposits discussed in the shallow and coastal-shallow depositional settings.

Carbonaceous shales host precious metal mineralization. In sulfidized and tectonically altered rocks, the gold and silver contents reach mineable grades; thus, the Kamensk structure appears to have a potential for a new gold object. Predicted gold resources calculated according to P3 category with an average grade of 0.3 g/t, comprise around 12.5 tons.

Acknowledgements

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Case Study of Permian Sedimentary Rocks Using 2D Shallow Seismic Survey on the Western Slope of the South Tatar Arch

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Abstract

The study of the structure and petrophysical parameters of the near-surface section sedimentary cover to a depth of about 250 m on the western slope of the Southern dome of the Tatar Arch, Tatarstan, Russia, has been of great importance in recent decades in connection with the beginning of the development of shallow-lying deposits of natural bitumen and super-viscous oil using SAGD technology. Due to the small depth of the deposits, it was necessary to develop a cost-effective technology for seismic survey, processing and interpretation of data that was within the research budget for drilling shallow appraisal wells. The article describes the features of the model parameterization for mathematical modelling of wave fields and the seismic technology developed. Its geological efficiency is demonstrated by examples of successful tracing of stratified reflecting horizons in the rocks of the Ufimian Stage and the Lower Kazanian Substage of the Perm system and the study of changes in the geological environment during the production of super-viscous oil using SAGD technology. Such studies are important because of the need for planning and effective application of development of heavy oil deposits using SAGD technology in order to avoid geohazards.

Keywords: shallow seismic, Permian system, oil sands, modelling, seismic processing, interval velocity

Introduction

The Permian system within the Southern dome of the Tatar Arch (STA), Tatarstan, Russia is represented by sediments of the Cisuralian, Biarmian, and Tatarian Series of the RGSS (Russian General Stratigraphic Scale), which hypsometrically belong to the upper part of a geological section sedimentary cover [1] called near-surface sections (NSS) in geophysics. The relevance of geological and geophysical studies of NSS on the western slope of the STA has been steadily increasing over the past decades. This is due to the involvement of natural bitumen and super-viscous oil (NB and SVO) in the exploration site located in terrigenous sediments of the Ufimian Stage (RGSS), the presence of oil seepages in the Middle Permian carbonate sediments and the need to monitor active exogenous and industry-related processes associated with the development of mineral deposits, especially when using thermal methods in heavy oil recovery. Analysis of several generalizing publications on the geological and geophysical characteristics of the NSS [2], [3] showed that the bulk of the information in Tatarstan was obtained from the interpretation of non-seismic methods of research of geological sections. NSS is a complex object for studying using seismic survey on reflected waves, due to the instability of their petrophysical parameters in the lateral and vertical directions, low reflection coefficients from the boundaries, and the absence of established links between petrophysical parameters and well logging data. Only a small amount of experimental and methodological seismic studies on NSS in Tatarstan was performed at different times by [4], [5], which
demonstrated the possibility of studying the Ufimian and Middle Permian strata by seismic prospecting, but for this purpose a special shallow seismic survey need to be developed.

Systematic development of this methodology was carried out from 2013 to 2018 at the Department of Geophysics at Kazan Federal University by the authors of the article, within the framework of Mega-grants of the Ministry of Education and Science of the Russian Federation (project No. 02.G25.31.0029, project No. 02.G25.31.0170). This article presents the results of application of this methodology to tracing stratigraphic boundaries, and technogenic impact on NSS within the Cheremshan-Barstrick group of super-viscous oil deposits of the western slope of the STA.

Methodology

Modelling

Mathematical modelling of wave fields within the NSS is an important tool for understanding their structure. The main problem arising in the simulation of the wave field for this interval of the geological section, hosting heavy oil-bearing reservoirs, is associated with its insufficient parametric support in the construction of the model.

The geometry of the model is formed based on the developed methodological technique [6] using the geographic information system Desktop ArcGIS. We have developed two approaches to the parameterization of the geological environment, which are used depending on the amount of information available.

In cases when there are no direct measurements of seismic velocities in NSS wells, we used regression analysis methodology for estimating P-wave velocity, based on gamma-ray logs [7].

However, in this case velocities may be overestimated, since the correlation of velocity variation with specific attributes is generalized for the Tatar Arch. Adjustment of the velocity model for a specific object (for example, an oil pool) is possible when interpretation of inverted travel-time curves for first waves is available. Velocities and bed thickness obtained from the interpretation allow the weighting coefficients by which the velocities in the model are adjusted to be calculated. Details are set forth in [6].

The best results can be obtained when sonic logging is undertaken in shallow (appraisal) wells, and when they are then used for seismic monitoring on the reservoir under development.

In this case, a downhole monitoring module is placed at the bottom of the well to record the travel time of the direct down going wave [8]. Elastic parameters of the beds are determined of the sonic and density logging data. When calculating velocities for the model, it is necessary to apply a reduction factor, since in sonic logging the velocities are usually inflated due to their dispersion. To clarify the reduction factor, mathematical modelling is performed using the Tesseral PRO (Tesseral Technologies Inc.) program to calculate the travel time of direct down going waves from the surface to a seismic downhole monitoring module. These calculated times are then compared with actual observed data. If they do not match, the velocity in the model is corrected. Several computational iterations are sequentially performed until the correspondence of the model and observed times is achieved.

To illustrate the methodological approach outlined above, consider the example of building a seismic-geological model of one of the SVO fields of the Cheremshan-Barstrick Group. Based on the available data of sonic and density logging, the acoustic impedance was calculated for each bed. When calculating the velocities, a reduction factor of 0.8 was applied. Further, the reflection coefficients were calculated. The depth interval of geophysical logging is 50÷200 meters, so the model includes only the Ufimian and Kazanian beds. The Ufimian stage in the model is represented by the Sheshmian Horizon. The top of the Kamyshla Beds of the Lower Kazanian Substage lies at a depth of 120 m.
The reflection coefficients for some boundaries reach a value of 0.2÷0.25 (Fig. 1), so they can be used as reference marker horizons in the processing and interpretation of shallow seismic data. All these boundaries are confined to the Lower Kazanian Substage. There are also high reflection coefficients at depths close to 200 m, but they cannot be the reference ones, since these are the boundaries of interbedding thin (in the seismic sense) layers.

Fig. 1. Horizons with relatively high reflection coefficients: 1 – boundary between Krasnyi Yar and Kamyslha Beds; 2 – boundary between the Kamyslha and Baitugan Beds; 3 – boundary associated with the top of the Lingula Shale Member of the Lower Kazanian Substage

The information obtained shows the prospects for the use of seismic surveys, promotes the development of methodology of field research, and allows wave fields to be stratified using the synthetic seismogram method.

Seismic profiling and time processing features

With shallow (100÷200 m) heavy oil deposits, application of surface-borehole 3D seismic technologies that already exist on the geophysical services market, for example [9], [10], significantly increases the cost of research and lead to unprofitable production in the Ural-Volga region, because the cost of heavy oil exploration using the conventional drilling method is much cheaper. Therefore, it was necessary to develop an economically efficient seismic technology adapted to the conditions of Tatarstan.

In the development of linear profiling techniques for shallow seismic exploration, the main attention was paid to the possibility of weathering zone study using the first wave arrival times.

This is because during the processing of shallow seismic seismograms obtained on the western slope of the STA, it is not possible to optimize the static corrections using the reference seismic horizons due to their unstable correlation. The only effective technique is an approach based on the use of first arrival times. For this, it is necessary to ensure registration of energetically expressed first arrivals to the offsets of 300 m with a small distance between the receiver points on the profile. Also, the procedure should ensure the possibility of recording seismic events before the recording time of about 0.35 s. Based on the results obtained by experimental work on the heavy oil pools of the Cheremshan-Barstrick group, we adopted for the profile survey flank 48 channels acquisition geometry with the 50 source impacts on a shot point. The receiver spread length is 188÷282 m at a distance between receiver and shot points 4÷6 m. Record length is 3000 ms at a sample rate of 0.25 ms. Electromagnetic source “Enisey EM-1,6” (Geotech) and telemetric data acquisition system XZONE Fly Lander (SI Technology)
are used in seismic surveys. On the raw seismograms typical of the Cheremshan-Barstrick group of NB&SVO fields, surface and first wave arrivals prevail.

A characteristic feature of shallow seismic seismograms recorded on the western slope of the STA is the imposition of an intense train of surface waves on the time interval for the recording of target reflected waves. Therefore, when developing the workflow, the most attention was paid to the effective suppression of surface waves, without creating a spatial aliasing effect, while maintaining the relative amplitude level on the traces.

The Paradigm® Echos®17 (Paradigm Geophysical) system was used for seismic processing. Using conventional pre-processing procedures, raw data are prepared to calculate the statics and optimize kinematic corrections. The first waves are used to calculate the statics.

An algorithm based on neural networks is used for picking. Using the arrival times of these waves, static corrections are calculated for the shot and receiver points. An important element of the workflow is the “LIFT” technology (Paradigm Geophysical). Our version of this technology combines modules oriented for the suppression of random, intense harmonic, due to industry-related factors, and coherent noise.

Availability of the a priori law of $V_{\text{rms}}$ velocities in NSS is of critical importance at the initial stage of optimization of kinematics. This is due to the need to suppress relatively intense residual energy of the first waves after “LIFT”, which makes it difficult to trace the weak reflected waves. It has been shown that the most effective means of suppressing the residual energy of first waves is parabolic Radon-filtering. However, for its application it is important to know the velocity close to reality in order to avoid errors during filtering. For this, the interval velocities obtained from the sonic logging are recalculated into $V_{\text{rms}}$ velocity for the profile being processed, considering the reduction factor. The presence of sonic logging data contributed to the elimination of ambiguity in the choice of velocities at the initial iterations.

The core of dynamic processing with relative amplitude preservation is a procedure based on the principle of surface consistency, including prestack deconvolution in the log/Fourier spectrum domain and amplitude balancing. The processing was completed with CMP stacking, and coherent residual noise filtering.

Results

Within the drilled area of the Ashalchinskoye Field of the STA, a profile consisted of 97 observations by the micro-CDP method worked out using the flank (48 channels) observation system and the number of accumulations on one shot-point equal to 50 impacts. The distance between the receiver points was 5 m. A productive Sandy Member of the Sheshmian horizon of the Ufimian Stage (RGSS) was the object of study. Refracted and surface waves strongly dominated on raw seismograms. Processing of raw seismograms was oriented for extracting refracted and reflected waves. The configuration of reflecting boundaries in the Ufimian – Lower Kazanian strata was studied using reflected waves. These boundaries were stratified using log data and a synthetic seismogram method. On the time section with distance between CMP points equal to 2.5 m (Fig. 2), the surfaces of the top of Lower Kazanian Substage, the top of Baitugan Beds, the top and the base of the Sandy Member are traced. The obtained result shows that with the seismic data processing aimed at the very top of the geological section, it is still possible to form a time section suitable for correlation. Qualitative and quantitative analyses of such time sections show the integrity of the caprock, reveal tectonically weakened zones, and estimate the probability of caprock failure and steam release. This information is relevant when planning the exploration of heavy oil pools using thermal recovery, especially for assessing possible environmental risks.
Some monitoring seismic survey materials were considered on a line traverse, laid through an SVO reservoir hosted in the Sandy Member of Sheshmian horizon, which is being developed using SAGD technology. The purpose of monitoring surveys is to measure attributes of the reflected waves observed on a heavy oil pool subjected to steam flooding. Time sections with relative amplitudes preserved and interval velocity models are built using the above processing sequence for base and monitor surveys.

Below the changes in the geological environment that occurred during the period from August 2016 to May 2017 are considered at a qualitative level. The most informative and interpretable observations for this period of monitoring are the interval velocity models.

The velocity model for 2016 recorded the formation of a heated zone in the central part of the traverse, associated with the operation of injection wells 20831, 20833. At the time of the base survey, the warm-up process in the zone of the location of the injectors was only indicated by narrow local low-velocity zones. In 2017, the active development of two heating zones, due to the work of the injectors 20827, 20829 and 20835, was recorded, which were not recorded in 2016. The obtained interval velocity differences between surveys were compared with the volumes of steam injection into the reservoir. These volumes can be divided between “Research 1” and “Research 2”. Research 1 covered the period from 01/01/2016 to 09/01/2016. Research 2 – from 09/01/2016 to 05/01/2017. Steam injection into the SAGD wells 20831 and 20835 was carried out between Research 1 and 2 (Fig. 3A). Accordingly, on the graph of the interval velocity difference (Fig. 3B) anomalous zones are highlighted. This result allows the analysis of spatial evolution of the heated zones from August 2016 to May 2017. There is a good coincidence of the identified velocity anomalies with the direction of technological events in the reservoir development for a specific time period.
Effective approaches to building a model of the environment for NSS with incomplete parametric data are developed. For accurate stratigraphic correlation of reflections on shallow seismic time sections, it is highly desirable to perform borehole seismology in NSS in the zones of occurrence of productive strata containing SVO.

The seismic and geological conditions of the western slope of the STA allow the Ufimian and Lower Kazanian rocks to be imaged reasonably well using reflection seismic waves. Therefore, if there are sufficient appraisal and structural wells with logging records, it is possible to study wave field morphology, to attempt to trace acoustic boundaries in geological layers, and to identify zones of decompression and paleokarst. It is also possible to obtain information on the condition of the Earth’s interior using reflected waves for shallow deposits of NB & SVO in the zone of temperature influence on rocks.

Thus, the method of shallow seismic exploration that we have developed is effective for studying structural features of Ufimian and Lower Kazanian strata, and for monitoring changes in the fluid condition in the zone of steam-thermal impact.

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First Conodont Apparatus Fragments in the Kasimovian Sediments of the Usolka Section (Southern Urals)

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Abstract

Using X-ray computer microtomography, we study several autochthonous burials of conodont apparatus fragments from Kasimovian Stage deposits of the Usolka section (Southern Urals). Tomographic 2D and 3D images allow visualization of conodont elements embedded in the host rock. A model of the conodont apparatus was reconstructed using computer microtomography.

Keywords: conodont apparatus, X-ray microtomography, Streptognathodus, Gondolella, Idiognathodus, Kasimovian, Usolka, Southern Urals

Introduction

The fossil record usually preserves isolated dentoid remains of conodont animals, while natural accumulations of conodont elements (in situ) in the form of a whole apparatus or its separate articulated fragments are much less common ([1], [2] and others). The integrity of a whole conodont apparatus is disturbed by numerous factors during fossilization. First, this is driven by the construction of the conodont apparatus, which consists of individual elements (conodonts) and, after the death of an animal and the decomposition of soft tissues, is most often destroyed. In addition, the search for conodont apparatuses is difficult because of the small size of the conodonts (usually up to 1 mm). Detection of the whole apparatus is also not facilitated by the method of isolating conodonts by dissolving rocks in acetic and other acids; as a result, the apparatus inevitably disintegrates into individual elements. Preservation of conodont apparatuses is also influenced by the conditions that existed in the sedimentary basin.

In our opinion, sediments formed in the deep sea with calm hydrodynamics and a soft muddy bottom are the most perspective for the search for conodont apparatuses, because of the low chance of destruction.

Material and Methodology

We focus on conodont apparatuses from the Usolka section, located near the village Krasnousolsky of the Republic of Bashkortostan in the axial part of the Ural trough (Fig. 1). It has been studied comprehensively and in sufficient detail ([3], [4] and others). The section does not contain gaps in the sedimentation; it is represented by carbonate and argillaceous deposits that accumulated in the Late Carboniferous era in a deep-sea environment [5].

A traditional processing technique was used to extract conodonts from limestones, dolomites and clays of the Usolka section [6]. Hereby, the most densely lithified clayish rocks (argillites) were soaked in water, then gently kneaded by hand, washed from clay particles, dried and sieved. The remaining large fraction (up to 1 cm) was viewed under the binocular. Sometimes conodonts embedded in rock were found in such fragments (Fig. 2), which could not be extracted by chemical methods. The method of X-ray microtomography was used to study...
them. This method is based on measuring the difference in the attenuation of x-ray radiation by individual components of the rock with different densities, and it allows to study the internal structure of micro-objects without their destruction.

![Fig. 1. Location of the Usolka section and sampling sites. Legend: 1 – limestone; 2 – clay, shales, mudstones; 3 – tuffs, 4 – location of the Usolka section](image)

The samples have been studied in the laboratory of computed tomography of the Kazan (Volga Region) Federal University, using a Phoenix V tome X S240 system. Samples were scanned on a nano-focus tube at an accelerating voltage of 70 kV and a current of 120 mA. We studied 4 samples from Kasimovian Stage deposits of the Usolka section with conodont fragments protruding from the rock (Fig. 2).

![Fig. 2. In situ conodonts in matrix. A – conodonts; B – matrix; a - sample No. Us-7.57; b No Us – 16.25; c No. Us – 8.43](image)

**Results and Discussion**

Conodonts have a homogeneous mineral composition of fluorapatite. The apatite density is about 3 g/cm³, whereas the carbonatic-clayey-siliceous rocks of the Kasimovian Stage have a density of 2.427 g/cm³ [7]. The X-ray density of the mineral phase of conodonts is 5-10 times higher than that of the host rocks. In recent years, the method of the X-ray computed tomography has begun to be widely used in Russia to detect and study conodonts in sedimentary rocks [[1] and others]. The authors of these studies, however, followed the task of finding conodonts in siliceous and carbonate-siliceous rocks in order to identify their generic (and even species) affiliation. We are addressing a different question by means of X-ray tomography: the search for the in-life conodont apparatus, as preserved in the rock, using to the sample processing technique described above.

As a result of our investigations, we were able to discover several autochthonous burials of conodont fragments.
The first conodont cluster (Fig. 3) was found in gray argillites of the bed No. 11 (sample No. Us-6.9) (the section is described in [8]). It contains two (left and right) articulated platform-type (P₁) conodont elements of *Gondolella magna* Stauffer et Plummer (Fig. 3). The co-occurrence of two conodont elements of the same species (*Gondolella magna* Stauffer et Plummer), perfectly corresponding each other in external morphological characters, their good preservation, lack of rounding and external damage (Fig. 3b) indicate that they belong to the part of the apparatus of one conodont animal.

![Fig. 3. Sample No. Us-6.9, articulated platform (P₁) elements of Gondolella magna Stauffer et Plummer: a, b) – volumetric tomographic images of articulated elements and the unfolded half of Gondolella; c, f) – cross section of Gondolella; d, e) – longitudinal section of Gondolella](image)

Another example of autochthonous burial of conodont elements is the second cluster (bed No. 13, sample No. Us-7.57); represented by two conodonts of the species *Swadellina subexcelsa* (Alekseev et Goreva) found together (Fig. 4). The joint finding of left and right elements of the same type (Fig. 4) evidences the fact that they represent the part of a single conodont apparatus. The possibility of such an accidental burial, in our opinion, seems extremely unlikely.
The third cluster is found in bed No. 15 (sample No. Us-8.43) and is represented, in our opinion, by a natural association of conodont elements (Fig. 5).

In the conodont apparatus, a certain sequence of arrangement of elements is observed [9]: the front part of the apparatus is composed of S- and M-type elements, the central part is composed of Pb elements, and there are Pa elements in the rear end. The burial has a similar set of conodont elements and is represented by two P₁ elements, identified as *Idiognathodus sp.*, one P₂ element and several S and M elements (Fig. 5, b, d). All elements lie in one plane at a small distance from each other. Probably, they are parts of a single apparatus, the elements of which “scattered” in the process of burial; perhaps this happened under the influence of weak near-bottom currents. An example of a similar finding of a conodont apparatus, consisting of scattered elements, is presented in [10].

In the fourth sample from bed No. 48 (sample No. Us-16.25), a platform conodont *Streptognathodus sp.*, a fish tooth and a fish scale were found (Fig. 6). This burial is allochthonous.
Fig. 5. Sample No. 8.43: a) – tomographic section of the accumulation of conodont elements in matrix; b) – volumetric tomographic in-situ images of the cluster of conodont elements; c) – a schematic representation of a conodont animal; d) a model of the conodont apparatus, reconstructed from the elements found in the Us-8.43 sample.

Fig. 6. Sample No. Us-16.25; A – fish scale; B – conodont; C – fish tooth; a) – volumetric tomographic images of the conodont, tooth and fish scale in situ; b) – conodont *Streptognathodus sp.* in matrix; c) – volumetric tomographic image of the conodont *Streptognathodus sp.*

**Conclusion**

Summarizing the results of studying conodonts from the Kasimovian deposits of the Usolka section using X-ray diffraction, we can conclude that deposits formed in relatively deep-sea conditions are the most perspective for detecting conodont apparatuses. 2D and 3D images obtained by X-ray microtomographic methods made it possible to visualize conodont elements.
embedded in the host rock and to confirm the so far proposed structure of the conodont apparatus. Studies have shown that it is efficient to search for conodont apparatuses using the X-Ray microtomography, which has demonstrated high efficiency: three of the four samples studied contained autochthonous conodont burials. No doubt remains on the applicability of X-ray microtomographic methods for search and detection of whole conodont apparatuses. The method provides the paleontologist with a wide range of high-quality graphic material that is suitable for solving taxonomical, phylogenetic and paleoecological problems.

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Trace Elements in Quartz as Geochemical Indicators of the Sources of Terrigenous Material in Conglomerates

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Abstract

The goal of the present paper is to show that high-precision geochemical analysis (LA-ICP-MS) can be used to cast light on the origin of quartz pebbles in quartz (or polymict) conglomerates. In the approach described, data on trace and rare-earth element concentrations in the pebbly quartz in conglomerates are was correlated with trace element concentrations in quartz from model geological units of known genesis from which terrigenous material could have been derived.

Keywords: quartz, trace and rare elements, conglomerates, LA-ICP-MS

Introduction

The determination of sources of the terrigenous (pebbly) material in sedimentary rocks is one of the problems in challenges of sedimentology [3]. Such reconstructions are commonly based on the detailed petrographic and geochemical studies of clastic material from sedimentary rocks. If sedimentary rocks (conglomerates) contain terrigenous quartz clasts (pebbles), then reconstruction of their primary origin requires more further detailed chemical study, e.g., the study of their trace element concentrations or a micromineral analysis of accessory phases, inclusions, etc.

Numerous geochemical studies of quartz, which is present in many igneous, sedimentary, and metamorphic rocks, show that data for its trace elements can be used to approach solve various geological and petrological problems [1].

Materials and Methods

The study was carried for a key section of Paleoproterozoic Karelian polymict conglomerates (Suna River canyon and adjacent area) [2], [4], [5]. Conglomerates in a 25-30 m thick sedimentary sequence are interbedded with gravel stones, inequigranular sandstone and siltstone (Fig. 1). The conglomerates are dominated by quartz pebbles (locally up to 90%); graphite schist and underlying basalt pebbles are also present. The matrix of the conglomerates consists of quartzitic sandstone with chemogenic iron-cherty impurity. Quartz pebbles of all visually identified types, varying in size from between 1 and 3 to 20 cm, were sampled laterally and in the up section from of the various zones of the conglomerate sequence.
The set of reference samples consists of vein and rock-forming quartz from the well-studied Mesoarchean and Paleoproterozoic rock complexes in Central Karelia which underlie the conglomerates. It includes samples of genetically contrasting quartz varieties which are characteristic of the various conditions of formation of quartz-bearing rocks formation: igneous (porphyric phenocrysts from andesite lava and subvolcanic dacite); post-magmatic (quartz amygdales from andesite-basalt); chemogenic (silicite); hydrothermal (quartz from gold bearing and barren veins); pegmatitic (quartz from muscovitic pegmatite) and terrigene-metamorphogene (quartzite).

Trace and rare-earth elements in quartz were identified on a X-SERIES-2 Thermo scientific quadrupole mass-spectrometer with an UP-266 Macro Laser Ablation attachment (New Wave Research) in the Institute of Geology of the Karelian Research Centre of the Russian Academy of Sciences following the method described in [6]. Analysis was performed on quartz plates measuring 1×1 cm. The laser sampling area size was 100×50 μm. To obtain statistically valid results, measurements were made along the profile at five points for each sample and then averaged.

Results and Discussion

The results of the studies show that all the quartz varieties contain many trace elements: Li, Be, Rb, Sr, Y, Zr, Nb, Sn, Ba, Hf, Ta, Th, U, REE. The concentrations of some of the elements in various quartz types vary substantially from significant high values to the lower sensitivity limit of the ICP-MS method. Trace element concentrations in various types of quartz are shown in Table 1.

Table 1. Trace element concentrations of the vein and rock forming quartz samples by LA-ICP-MS, ppm

<table>
<thead>
<tr>
<th>Quartz type</th>
<th>Magmatic</th>
<th>Postmagmatic</th>
<th>Chemogenic</th>
<th>Terrigene-metamorphogene</th>
<th>Hydrothermal</th>
<th>Pegmatitic</th>
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<tbody>
<tr>
<td>Elements</td>
<td>Q26</td>
<td>Q25</td>
<td>Q1</td>
<td>Q2</td>
<td>Q24</td>
<td>Q19</td>
</tr>
<tr>
<td>Li</td>
<td>12.3</td>
<td>5.75</td>
<td>5.54</td>
<td>6.32</td>
<td>5.59</td>
<td>4.35</td>
</tr>
<tr>
<td>Be</td>
<td>3.54</td>
<td>1.73</td>
<td>0.10</td>
<td>0.17</td>
<td>1.86</td>
<td>1.21</td>
</tr>
<tr>
<td>Rb</td>
<td>162</td>
<td>19.4</td>
<td>1.00</td>
<td>13.2</td>
<td>71.1</td>
<td>84.9</td>
</tr>
<tr>
<td>Sr</td>
<td>39.3</td>
<td>200</td>
<td>0.95</td>
<td>0.50</td>
<td>35.7</td>
<td>20.5</td>
</tr>
<tr>
<td>Y</td>
<td>12.8</td>
<td>7.96</td>
<td>0.12</td>
<td>0.19</td>
<td>28.5</td>
<td>20.2</td>
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<tr>
<td>Zr</td>
<td>108</td>
<td>60.8</td>
<td>0.27</td>
<td>0.58</td>
<td>99</td>
<td>100</td>
</tr>
<tr>
<td>Nb</td>
<td>10.9</td>
<td>8.26</td>
<td>0.08</td>
<td>0.52</td>
<td>19.7</td>
<td>7.59</td>
</tr>
<tr>
<td>Sn</td>
<td>2.89</td>
<td>1.04</td>
<td>1.45</td>
<td>1.15</td>
<td>1.60</td>
<td>0.80</td>
</tr>
<tr>
<td>Ba</td>
<td>580</td>
<td>340</td>
<td>0.39</td>
<td>21.4</td>
<td>217</td>
<td>260</td>
</tr>
<tr>
<td>La</td>
<td>10.6</td>
<td>4.06</td>
<td>0.22</td>
<td>0.12</td>
<td>0.94</td>
<td>0.43</td>
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</table>
The spider grams of trace element concentrations in various quartz types, normalized for the composition of the upper continental crust (UCC) [3], show considerable differences in trend topology and the pattern of the anomalies observed (Fig. 2, a-c). Three distinct quartz types, which differed both in the degree of enrichment of rare and rare-earth elements, and their concentration ratios, were determined using the studied collection. The first group is represented by magmatic quartz; the second group is made up of hydrothermal, post magmatic and pegmatitic quartz; the third group join chemogenic and terrigene-metamorphogene quartz.

Trace element concentrations in pebbly quartz from the conglomerates are shown in Table 2. The geochemical composition of quartz from pebbles was shown to be heterogenous: the concentrations of Ba, Th, Rb, Sr, Zr and some other elements vary markedly.
Comparison of trace element distribution trends in the pebbly quartz of the conglomerates with type trends for reference quartz samples has revealed two key varieties in the pebbles (Fig. 3) which correspond to hydrothermal (1) and terrigene-metamorphogene (2) quartz. This conclusion indicates the existence of at least two sources of transportation of clastic quartz into the sedimentary basin. Quartz pebbles of type 1 could have been formed by the destruction of hydrothermal quartz veins and quartz-bearing amygdaloidal rocks of the Paleoproterozoic andesite-basalt volcanic complex. The source of quartz of type 2 is associated with Archean quartzites.

**Fig. 2.** Rare and REE patterns (normalized to UCC) of the pebbly quartz from conglomerates [3]

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<tbody>
<tr>
<td>Li</td>
<td>2.53</td>
<td>2.27</td>
<td>2.65</td>
<td>3.04</td>
<td>2.03</td>
<td>1.97</td>
<td>2.57</td>
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<td>3.48</td>
<td>3.41</td>
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<td>Be</td>
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<td>0.15</td>
<td>0.25</td>
<td>0.17</td>
<td>0.11</td>
<td>0.23</td>
<td>0.11</td>
<td>0.38</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
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<tr>
<td>Rb</td>
<td>15.63</td>
<td>1.48</td>
<td>1.26</td>
<td>1.55</td>
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<td>1.75</td>
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<tr>
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<td>0.04</td>
<td>0.09</td>
<td>0.06</td>
<td>0.05</td>
<td>0.08</td>
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Conclusions

Thus, groups of quartz, geochemically contrasting in trace and rare-earth element distributions, were identified using reference quartz samples of Central Karelian rock complexes as an example. Comparison of the chemical composition of terrigenous clastic
quartz from conglomerates with the composition of reference quartz samples makes it possible to reliably identify the sources of its transport (parent rocks). Our study shows that high-precision geochemical analysis (LA-ICP-MS) can be performed to throw light on the origin of quartz pebbles in sedimentary rock sequences, and that this analysis is advantageous for the geodynamic reconstruction of the formation and evolution of sedimentary basins.

Acknowledgements
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REFERENCES

Upper Devonian *Cristatisporites Deliquescens* Palynozone and its Correlation (Timan-North Urals Region)

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**Abstract**

Currently, there is a debate about the age relations of the new *Cristatisporites deliquescens* Palynozone with respect to the existing miospore and conodont zonations. The new zone occupies a level between the *Cristatisporites pseudodeliquescens* and *Geminospora semilucensis* – *Perotrilites donensis* zones in the regional scheme of the Devonian palynostratigraphic zonation. The lower part of the *Cristatisporites deliquescens* Palynozone corresponds to the *Ancyrodella rotundiloba soluta* conodont Zone. Spores, conodonts, and ostracodes characteristic for this new biostratigraphic interval are discussed.

**Keywords:** Spores, Conodonts, Ostracods, Upper Devonian, lower Frasnian, Timan-North Urals Region

**Introduction**

The Timan-Pechora Province is providing excellent sections that include conodonts, ostracodes and spores, and as such, provides the opportunity to propose new regional stratotypes to clarify the lower boundary of the Frasnian stage (i.e., the Middle and Upper Devonian boundary). As such, these Mid-Late Devonian boundary sections are unique and internationally important. Taxonomic diversity and good preservation of micro- and macrofossils of various organisms can serve as a basis for comparing these sections, including regional and interregional correlations. Palynological analysis is the main tool for the biostratigraphic subdivision of continental and marginal marine deposits. However, it is essential to compare these palynological zones with the marine invertebrate standard zonations for regional and especially interregional correlations with conodont zonation being the prime tool for Devonian subdivision. In this paper we show a correlation of the new regional *Cristatisporites deliquescens* Palynozone with the conodont zonation (Fig. 1). Along with the zonation we will present the spore, conodont and ostracode assemblages that characterize the Lower Frasnian deposits of the Upper Devonian (i.e., slightly above the lower boundary of the Frasnian stage).
Fig. 1. Middle to Upper Devonian correlation of conodont, ostracodes and palynological zones compared with the timing of global events

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**Material and Methods**

The article describes the analysis of the results of palynological and paleontological studies of the Devonian sediments based on materials from the Middle and Southern Timan and Chernyshev Ridge (Fig. 2). In the Middle Timan (Tsilma River Basin), Lower Frasnian deposits are represented by continental facies of the Ust-Yarega Formation. They are almost ubiquitous in the territory of the Middle Timan. In Southern Timan, Lower Frasnian deposits are represented by shallow-water facies of the Ust-Yarega Formation (Ukhta Region) and the Yba Formation (Ust-Kulom Region, Shera Creek section). The Chernyshev Ridge (Dershor Creek section) is where the deepest Lower Frasnian deposits are found in in the Timan-Pechora Province. They are represented by clay-carbonate facies of the Kedzydshor Formation.
Fig. 2. Locality map of the sections studied in the Timan-North Urals Region. 1 – Tsilma River sections (Middle Timan), 2 – Dershor Creek section (Chernyshev Ridge), 3 – sections of Southern Timan (Ukhta Region), 4 – Shera Creek section (Southern Timan, Ust-Kulom Region)

The samples for palynological analysis was processed using new technologies and methods [1], [3]. Importantly the method of processing Paleoozoic continental deposits, which contain coal was upgraded. Now it is more chemically stable than the spores associated with it. The method allows to recognize palynospectras with rich, and diverse taxonomic compositions, which contributes to the definition of palynostratigraphic assemblages. The specimens were studied in transmitted light on a Biolam-I biological microscope equipped with a Canon PowerShot A95 digital camera under magnification of x400, x600, and x1000 using a cedar immersion oil.

Conodonts and ostracods were isolated from carbonate rocks by dissolving in 10% acetic acid with the addition of a buffer solution. Clay rocks were soaked in water and washed through a 0.05-0.1 mm sieve. Some samples for ostracods were dissolved in glacial acetic acid [2]. The fauna was photographed using a Tescan Vega 3 LMH scanning electron microscope.

Results

During the last few decades little work has been focused on improving the regional Stratigraphic Devonian Scheme. Nevertheless, rich paleontological and stratigraphic material has been collected, and is available for integration and systematization. It is important to use the palynological method for the subdivision and correlation of continental and marginal-marine deposits. However, for regional and especially interregional correlations it is essential to compare palynological zones with other zonation’s. Most of all, comparing with the key zonal groups of organisms (in the Devonian Stratigraphic Scheme – by conodont and ammonite zonation). Such a comparison has become possible for the Lower Frasnian interval of the section, somewhat higher than the boundary between the Givetian and Frasnian stages and has greatly increased the importance of our research.
The sequence of palynocomplexes (PC) from the continental Givetian-Frasnian deposits in the Tsilma River basin (Middle Timan) is described and correlated with complexes of synchronous marginal-marine Southern Timan [3]. Two sub-complexes (A and B) are clearly identified from the Ust-Yarega Formation. Sub-complex A is dominated by small spores of Archaeopteris plants with tuberous external surfaces: Geminospora micromanifesta (Naumova) Owens, G. micromanifesta (Naumova) var. collatatus Tchib., etc. Megaspores (G. macromanifesta (Naumova) Owens, Contagisporites optivus (Tchib.) Owens occur as 2-3 specimens per sample). Spores with a relatively wide zona: Calyptosporites domanicus (Naumova) Oshurk., C. bellus (Naumova) Oshurk., Cristatisporites pseudodeliquescens Telnova et Marshall, C. triangulatus (Allen) McGregor et Camfield, Ancyrospora melvillensis Owens, A. laciniosa (Naumova) Mants., A. ampulla Owens are subdominant. Spores with sculptured and tuberous surface of the sporoderm are represented by a small number of specimens and low diversity species composition: Acanthotriletes bucerus Tchib, Ac. similis Naumova, Ac. eximius Naumova, Lophozonotriletes scurrus Naumova, Converrucosisporites curvatus (Naumova) Turnau; patinate forms Archaeozonotriletes variabilis Naumova and Ar. variabilis Naumova var. insignis Sen. are rare. The PC of sub-complex A from outcrops of the Tsilma River basin characterize the early Sargaevo age. Similar PC assemblages were studied in outcrops of the lower part of the Ust-Yarega Formation of the Southern Timan and have been traced in other areas of the Timan-Pechora Region [4].

Sub-complex B (Fig. 3) is characterized (as well as subcomplex A) by an abundance (50-80%) of small-tuberous spores of the Geminospora genus with great species diversity. The spores with a fine relatively wide zona are subdominant (20-40%) (as well as in sub-complex A): Densosporites sorokinii Obukh., D. meyeriae Telnova, Cristatisporites timanica Telnova et Marshall, C. deliquescens (Naumova) Arkh., C. pseudodeliquescens Telnova et Marshall, C. triangulatus (Allen) McGregor et Camfield, C. trivialis (Naumova) Obukh., Ancyrospora melvillensis Owens, A. laciniosa (Naumova) Mants. Other spore taxa of higher plants are rare: from single specimens to 7%. These are spores with a sculptured wrinkled surface sporoderm, patinate: Ar. variabilis Naumova, Ar. tschernovii Naumova, Ar. latemarginatus (Kedo) Obukh., Ar. variabilis Naumova var. insignis Sen.; monolete: Archaeoperisaccus verrucosus Pask., Arch. timanicus Pask., Arch. concinnus Naumova, etc.
Fig. 3. Palynocomplex of the *Cristatisporites deliquescens* regional Zone (Tsila River sections).


The miospore sub-complex B is most similar to the PC extracted from the brownish gray clays of the Dubnikovsky Horizon (the upper part of the section of the Izborsk quarry, Pskov area, eastern part of the Main Devonian Field). The sub-complex B is mainly distinct from the older sub-complex A (early Sargaevo) (1) by the constant presence of the *Cristatisporites pseudodeliquescens* index species of PC of the Sargaevo Horizon, (2) the presence of typical Frasnian *Cristatisporites deliquescens* and *Archaeoperisaccus concinnus* species, (3) reduced numbers of spores of the *Cristatisporites krestovnikovii-C. bellus-C. domanicus* morphon and (4) the greater proportion of spores with a relatively wide zona (*Cristatisporites, Densosporites, Perotrillites*, etc.).

The simultaneous appearance of the spores *Cristatisporites deliquescens* (Naumova) Arkh. and the conodont *Ancyrodella rotundiloba soluta* Sandb., Zieg. et Bult. in the upper part of the
Kedzydshor Formation in the Dershor Creek section (Chernyshev Ridge) was investigated for the first time [5], [6].


This palynocomplex differs from the spore complex isolated from underlying deposits by a high percentage of spores (24%) with a thin, filmy external layer, their species diversity (*Cristatisporites*, *Ancyrospora*) and the first appearance of species *Cristatisporites deliquescens* (Naumova) Arkh. and *Archaeoperisaccus mirus* Naumova.

This section interval beds with *Ancyrodella soluta* were identified by A. B. Yudina [6]. She established a conodont association of a predominantly polygnathid composition (*Ancyrodella rotundiloba soluta* Sandb., Zieggl. et Bult., *Polygnathus pennatus* Hinde, *Pol. aff. alatus* Hinde, *Pol. dengleri* Bisch. et Zieggl., *Pol. aff. dubius* Hinde, *Pol. decorosus* Stauff., *Pol. xylus* Stauff.), which was assigned to the lowermost part of the lower subzone of the *Mesotaxis falsiovalis* conodont Zone [7], [8].

Since then, significant changes in the conodont zonation of the Devonian system have occurred. *Ancyrodella rotundiloba soluta* Sandb., Zieggl. et Bult. serves as an index species of the same name Zone in the upper part of the lower subzone of the *Mesotaxis falsiovalis* conodont zone [9], [10]. The *Skeletognathus norrisi* Zone and *Ancyrodella rotundiloba pristina* Zone are separated below this Zone, which are also a part of the lower subzone of the *Mesotaxis falsiovalis* conodont Zone.

A similar association of conodonts and miospores was encountered in the shallow-shelf facies of the Southern Timan (Djejimparma Swell). The Shera Creek section is represented by carbonate organo-detrital rocks. The appearance of the index-species *Mesotaxis falsiovalis* Sandb., Zieggl. et Bult. was recorded in the middle part of the section [11]. These conodonts characterize the base of the lower subzone of the *Mesotaxis falsiovalis* conodont zone [8], [10].


Fig. 4. Conodonts from the Shera Creek section (Ancyrodella rotundiloba soluta Zone)

1, 1a – Ancyrodella rotundiloba soluta Sandberg, Ziegler et Bultynck, upper and lower view of 492/18-4, sample 37; 2, 2a – Mesotaxis falsiovalis Sandberg, Ziegler et Bultynck, upper and lower view of 492/18-2, sample 38; 3, 3a – Ancyrodella rotundiloba rotundiloba Bryant, upper and lower view of 492/18-1, sample 39b; 4, 4a – Polygnathus webbi Stauffer, upper and lower view of 492/18-3, sample 41; 5 – Polygnathus cf. reimersi Kuzmin, upper view of 492/17-46, sample 37. Scale bar is 200 μm.

Ostracodes Acratina pestrozvetica Egorov, Gravia fabra Zaspelova shows last appearance in the Cristatisporites deliquescent Palynozone. Bairdia (Rectobairdia) aff. chalonensis Casier et Olempska and Nodella cf. sp. (sensu [12]) appears in this zone, but Bairdia aff. paffrathensis (Kummerow) has a wide stratigraphical range comprising this zone as well (Fig. 5). Using the ostracodes, this level can be compared with the lower part of the Ust-Yarega Formation of the Southern Timan [12]. The underlying deposits contain the Upper Timan ostracode association of the following taxonomic compositions: Nodella faceta Rozh., Acratina pestrozvetica Egorov, Gravia fabra Zaspelova, Bairdia aff. paffrathensis (Kummerow) and Schneideria schigrovskiiensis (Polenova) characteristic of the Cavellina devoniana ostracode Zone on the Southern Timan [12].
Fig. 5. Ostracodes from the Shera Creek section
(Cavellina devonianana and Cavellina chvorostanensis – Entomozoe (Richteria) scabrosa? Zones)
1 – Acratina pestrocyctica Egorov, juvenile carapace in right lateral view of 333/48-20, sample 20; 2, 5 – Bairdia aff. paffrathensis (Kummerow), (2) carapace in right lateral view of 333/48-45, (5) carapace in dorsal view of 333/48-44, sample 33a; 3, 6 – Gravia fabra Zaspelova, (3) left valve in lateral view of 333/48-49, (6) left valve in dorsal view of 333/48-50, sample 35a; 4 – Bairdia (Rectobairdia) aff. cholinensis Casier et Olempska, carapace in right lateral view of 333/50-55, sample 37; 7 – Schneideria schigrovskiiensis (Polenova), lateral view of right valve of 333/50-57, sample 35a; 8 – Nodella faceta Rozhd., tecnomorph right valve in lateral view of 333/50-50, sample 35a; 9 – Nodella cf. sp. (sensu Yudina et Moskalenko), lateral view of left broken valve of 333/48-59, sample 37a. Scale bar is 200 μm.

The Yba Formation of the Shera Creek section is the closest in quality to the stratotype Col du Puech dela Suque section in Montagne Noir in Southern France [13]. This section, in our opinion, is the most promising to confirm the level of the poorly defined boundary between the Givetian and Frasnian stages. Future studies will focus on detailed biostratigraphic dissection of the section, especially below the first appearance of Ancyrodella rotundiloba soluta Sandb., Zieg. et Bult. and Cristatisporites deliquescens (Naumova) Arkh.

The spores Cristatisporites deliquescens (Naumova) Arkh. in the stratigraphic complete sections of Middle Timan is highlighted as an index species of the miospore sub-complex B in the Cristatisporites pseudodeliquescens Zone [3]. The Cristatisporites pseudodeliquescens Zone was established in a continuous section of the 1-Balneological Borehole (Southern Timan) directly above the rocks containing the Upper Timan palynocomplex (in the lower part of the Ust-Yarega Formation) for the first time. There are few spores (10-12 species from 7 generations) in the phytocomplex of the upper part of the Ust-Yarega Formation, acritarchs of the genera Varyhachium, Baltisphaeridium, Michrystridium appear, which reflects a change in sedimentation conditions [5]. Unlike Southern Timan, the stratigraphic sequence of appearance in the section of the spore species Cristatisporites pseudodeliquescens Telnova et Marshall, Cristatisporites deliquescens (Naumova) Arkh., Geminospora semilucens (Naumova), Perotrilites donensis (Rask.) M. Rask. can be traced in the sections of the Ust-Yarega Formation of the Middle Timan.

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Conclusion

The association of the conodont Ancyrodella rotundiloba soluta Sandb., Zieg. et Bult. and the spore Cristatisporites deliquescens (Naumova) Arkh. was traced in different facies of the Timan-North Urals Regions and the sequence of appearing in the stratigraphic section of the spores Cristatisporites pseudodeliquescens Telnova et Marshall and Cristatisporites deliquescens (Naumova) Arkh., allows us to recognize the new regional Cristatisporites deliquescens Palynozone. This new zone occupies a level between the Cristatisporites pseudodeliquescens Palynozone (currently describing only the lower part of the Ust-Yarega Formation) and the Geminospora semilucentis – Perotrilites donensis Zone in the regional scheme of the Devonian palynostratigraphic zonation.

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REFERENCES

Biogenic and Abiogenic Disturbances of the Ordovician Invertebrate Shells of the Leningrad Region in the Collections of the Mining Museum

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Abstract

The article discusses the biogenic and abiogenic defects of Ordovician invertebrate shells from the east of Baltoscandia. Biogenic defects constitute a special group of ichnofossils, traces of life activity of epi- and endobionts. A study of the Ordovician invertebrate collections of St. Petersburg Governorate (collections of the 19th – early 20th centuries, supplemented by authors’ collections) allowed the authors to confirm the occurrence of an extensive assemblage of endobionts in the Sandbian deposits of the Leningrad Oblast – Trypanites Mägdefrau, Arachnostega Bertling, Petroxestes Wilson et Palmer, Cornulites Schlotheim. Previously these ichnotaxa were found only in more western regions of Baltoscandia (Estonia). We suggest that the ichnogenus Osprionides Beuck et Wisshak appeared at a lower stratigraphic level (Middle Ordovician). Abiogenic defects abundant in Ordovician invertebrates of Baltoscandia include Beekite rings, a special form of concentric-zonal silica aggregates. The frequent occurrence of Beekite rings on the shells of the brachiopod genus Porambonites Pander can be explained by particularities of shell structure and sculpture in this taxon.

Keywords: Ordovician, invertebrate shells, biogenic, abiogenic disturbances

Introduction

Deformations and incrustations on the surface of invertebrate shells are quite a valuable material both for taphonomic studies, and also for obtaining additional information about the characteristics of fossil biotopes. The first group of shell surface disturbances includes peculiar concentric-zonal silica aggregates. These so-called Beekite rings were considered by B.P. Markovskii to be an indicator of continental breaks [1]. Various ichnofossils (boring traces) and incrustations that occur on shells both during the life of animals and after their death represent the second group of deformations. Despite the fact that deformations and disturbances of shells often impede species diagnostics, they can also provide valuable information on the lost biotopes of the studied paleobasin.

Material and Methods

The Mining Museum houses collections of the Ordovician invertebrates collected back in the 19th and early 20th centuries in the territory of then Saint Petersburg Governorate, Courland, and Livonia. Among these collections, there are many collections of unknown authors, but there are also collections originally attributed to the collections of Ch. Pander, G. Helmersen, R. Hecker. Of particular interest are the alleged collections of Ch. Pander and his contemporaries, which (judging by archival data) could have been studied by Ch. Pander and E. Eichwald. In these collections, dating from the end of the first third to the middle of the 19th century, one can
find type species of many Ordovician invertebrates, first established by Ch. Pander, part of the collection for the monumental monograph by E.I. Eichwald “Paleontology of Russia”.

However, this huge amount of material is extremely difficult to attribute to the specified authors. Currently the museum is faced with the task of attributing a huge number of exhibits, which was finally launched with the active participation of the authors in 2018.

In the process of restudying collections, special attention was given to any deformations and incrustations (both biogenic and abiogenic in nature) that violate the surface of shells. Despite the fact that this direction arose in the works of N.N. Yakovlev, these studies have recently gained particular relevance in the light of the new stage in the study of ichnifossils on both biological and non-biological substrates. The material is represented by some samples from the collections of the Ordovician invertebrates of the Mining University: shells of rhychoonelliformea brachiopods, bryozoans, gastropods containing various ichnifossils.

Among the collections studied by the authors, there were collections of Silurian (Ordovician, authors’ notes) fossils of R. Hecker, collected in the twenties of the XX century in various districts of the Leningrad region (mainly the east of this region – the river Volkhov, and the west – the surroundings of Weimarn); and collections of various authors of the XIX century (Saint Petersburg Governorate and Estonia). From a stratigraphic point of view, the overwhelming majority of fossils were confined to deposits of the Kukruze regional stage (Sandbian). The material is supplemented by the authors’ collections from the Sandbian deposits of the west of Leningrad region.

In addition, the authors identified curious mineral aggregates complicating the surface of brachiopod shells (so-called Beekite rings) on specimens of pentamerids (rhychoonelliformea brachiopods) from the collections of the Mining Museum.

Since all samples with Beekite rings were represented only by samples from the Mining Museum, studies were possible without violating the integrity of the samples: X-ray microtomography and examinations of the surface of the shells under a binocular microscope.

The study of museum samples with ichnifossils was also carried out under binocular microscopes; thin sections were also made from the authors’ specimens.

**Geological Setting**

The conditions of the shallow epicontinental sea (located on the southwestern edge of the Baltic paleocontinent) dominated throughout the Ordovician period in the territory of the modern Leningrad region. Together with neighboring Estonia, the Leningrad region was a part of the shallowest North Estonian belt [2]. The change in the nature of sedimentation was due to eustatic fluctuations of the sea and the gradual migration of the paleocontinent from the high latitudes of the southern hemisphere to low latitudes. As a result of this, there are three main stages in the development of the Baltic Sea: the Pakerort (the end of the Cambrian – the first half of the Tremadocian), characterized by moderately cold conditions and a terrigenous sedimentation regime; the second stage, the Latorpian – the Keila (end of the Floian – beginning of the Katian), which was also characterized by moderately cold sedimentation conditions and by predominantly carbonate sedimentation; the third stage, the Oandu – the Porkuni (the Katian – the Hirnantian) which could be characterized by warm water carbonate sedimentation [3].

The shallow sea of the east of Baltoscandia turned out to be favorable for the biodiversification of many groups of animals: brachiopods, trilobites, bryozoans, and conodonts [4]. Obviously, in parallel with this parasite of these animals developed rapidly.
Theory

On the shells of the Ordovician invertebrates in the east of Baltoscandia traces of various epi- and endobiont organisms were recorded. The organisms of the endobionts left quite diverse morphological traces related to their various species. Irregular, branching traces of *Arachnostega* Bertling are widely developed and are found on the shells of bivalves, gastropods, cephalopods and chiolites throughout the Phanerozoic. It is believed that these parasitic animals were endosymbionts; there are two different interpretations regarding the ethology of organisms [5]. According to the first, the ethology of traces is considered from the standpoint of arranging a food place – *fodinichnia*, *agrichnia* or *chemichnia*. According to the second, these traces belonged to the *domichnia* group and were burrows of the animal. In the eastern Baltoscandia traces of Arachnostega were described by O. Vinn on fossils from the Middle and Upper Ordovician deposits of Estonia [6]. The most common species, *Arachnostega* is found in the Kunda deposits (the Darriwilian, about 17% of shells), less developed in the Sandbian deposits (11% of shells) and is extremely uncharacteristic of the Katian deposits (3% of shells) [6]. According to O. Vinn the sharp decline in the number of species of this genus was due to climatic changes; this is because the animal that left the traces preferred to live in a moderately cold-water sea.

There are two species, which are morphologically quite similar, of the Ordovician endobionts of Baltoscandia – *Osprioneides* Beuck et Wisshak and *Petroxestes* Wilson et Palmer, which are characterized by branchless, elongated holes, that are subcyindrical or subrectangular in cross section. Traces of *Osprioneides* differed from *Petroxestes* by significant difference between the hole depth and the width (25 mm and 15 mm along the axis respectively) [7]. Soft-bodied abdomens, possibly from polychaete worms, are indicators of organisms that make up *Osprioneides* traces. The ichnogenus *Petroxestes* can be found from the Upper Ordovician to the Miocene and is characteristic of both invertebrate shells and the surface of the hard bottom. In the Baltic *Petroxestes* was found in sediments of the Estonian Kukruze and Johvi regional stages (Sandbian). The ichnogenus *Osprioneides* is characteristic of the Upper Ordovician-Silurian deposits of the Baltic [8]. For Estonian Silurian deposits, it is assumed that Osprioneides are confined to the hard substrates that are comparative to the deep-sea conditions of the open shelf.

The inhabitants of other conditions included the species *Trypanites* Mägdefrau. The ichnogenus *Trypanites* includes narrow, cylindrical, unbranched traces that are found both on the surface of the hard bottom and in invertebrate shells. Trypanites are the most common drilling marks. The first traces of *Trypanites* were found in the Lower Cambrian sediments. *Trypanites* are found in the Baltic in sediments of all Ordovician divisions and in Estonian Silurian sediments [9]. Polychaetes worms are considered to be the most likely authors of these tracks, while the tracks are considered as *domichnia*, burrows. From an environmental point of view, clusters of traces of *Trypanites* on an abiogenic substrate are confined to hard ground.

An ecologically variable group, represented by both epibionts (mainly) and endobionts, are cornulitids, which are peculiar tentaculales. Cornulitids existed from the Middle Ordovician to the Late Carboniferous. The first endosymbiotic *Cornulites* of the Baltic were found in sediments of the Lasnamagi regional stage of Estonia (Darriwilian) and are represented by only one species of *Cornulites*? *semiapertus* Öpik [10]. During the late Ordovician, the number of Baltic cornulitids increased (3 in the Sandbian, 6 in the Katian). At the same time that cornulitids appeared on shells of invertebrates both during life and after death, their tubes were found on shells of trilobites, and on shells of brachiopods.

Paleoichnology is a relatively young area of paleontological research, which received intensive development only at the end of the 20th century. At the same time, attention was paid primarily to the ichnofossils and ichnostructures of rocks, and the study of ichnogenera recorded
on other fossils was actively started only at the beginning of the XXI century. Thus, now the knowledge of paleoendobionts and paleoepibionts associated with these traces is at the initial stage of development: the initial taxonomic affiliation of the genera is being developed, their stratigraphic and geographical significance, as well as their ethological features, are being clarified.

If the study of biogenic disturbances of the shells of the Ordovician invertebrates of the Baltic influences the expansion of ideas about the features of the biotopes of the paleoseas and also makes it possible to highlight additional stratigraphic benchmarks, then the study of abiogenic disturbances of shells is relevant, first of all, from the standpoint of identifying taphonomic features. These abiogenic disturbances also include concentric-secretion silica aggregates, the so-called Beekite rings. Despite the fact that the presence of such aggregates on the shells of the Phanerozoic invertebrates was known for a long time in domestic literature, they did not receive much attention and sometimes erroneous interpretations arose. Therefore, as mentioned above, B.P. Markovskii interpreted these formations as traces of the vital activity of lower plants [1]. Recently attention to such structures has been intensified in foreign literature, some taphonomic, paleogeographic, stratigraphic patterns of the formation of the described structures have been established, as well as the influence of the paleontological substrate on the nature of the arising silica aggregates [11]. In addition, information has appeared that indicates the location of horizons containing fossils with Beekite rings coincides with the position of stratigraphic breaks [12].

Results and Discussion

On the ventral and dorsal valves of the shells the Strophomenida *Bekkerina dorsata* from the Kukruse regional stage (Lower Sandbian) of Weimarn environs (collection by R.F. Gekker, the Mining Museum) found peculiar endobionts (Fig. 1). Numerous tubes (aperture diameter of about 2 mm, length 3 mm) have been observed in the shells. Currently only *Cornulites stromatoporoides*, which is widespread in the Wenlock deposits of Estonia, is known among the shell endobionts of the Lower Paleozoic of Baltoskandia. In addition to the incomparably lower stratigraphic level (the first cornulites of the endobionts appear in the Katian), the described forms differ in oval aperture.

![Fig. 1. Traces of the endobiont in the shell of *Bekkerina dorsata* (Bekker, 1921), Viivikonna formation, Kukruse regional stage, Lower Sandbian, neighborhood of Weimarn, presumably the collection by R.F. Hecker](image)

Judging by the presence of these endobionts on both valves of shells, as well as the nature of the interruption of the radial sculpture of brachiopods by holes, the settlers appeared on the shells after the death of the brachiopods. This also distinguishes them from the above *Cornulites*...
stromatoporoides, which is an endosymbiont. Numerous forms (similar to those available in the collection of the Mining Museum) were found by the authors on the shells and valves of brachiopods, cephalopods, sporadic on cystoid thecae in the Alekseevsky quarry and in the Dyatlitsy quarry in the sediments of the Viivikonna formation (Kukruse regional stage, Lower Sandbian). The majority of brachiopods with the described ichnofossils are confined to a layer of dense massive light brown (to cream) limestone. This layer is abundant in the diverse fauna of brachiopods, gastropods, bryozoans, pieces of the stems of crinoids, cephalopods (Orthoceratoidea), and extremely rare chiolites. The shells and shell fragments of *Porambonites (Porambonites) laticaudata* Bekker containing numerous ichnofossils of the indicated type are especially characteristic of the described layer (Fig. 2).

![Fig. 2. The “splices” of traces on the shell of *Porambonites (Porambonites) laticaudata* Bekker (the thin section). Viivikonna formation (Kukruse regional stage, Lower Sandbian), Alekseevsky quarry](image)

Tubes of these organisms have trapezoid and rectangular forms. In thin sections, their shape remains unchanged, only their preservation and size differ. Their size on the long side is from 0.45 to 2.2 mm, on the short side from 0.5 to 1.25 mm. It can be seen in thin sections that these organisms bored a shell around the edge and in the center, leaving the middle as a refuge. In addition, the remains of a translucent edge about 0.05 mm thick may indicate the nature of boring to be from the center to the edge with a gradual “beating” from the shell as they grow (Fig. 3).

By the nature of being on the shells they settle both individually (Fig. 3, in these cases they are the largest), and in groups, usually at some distance from each other, sometimes with an overlap (Fig. 2). It was not possible to precisely determine the depth of strokes during grinding; however, it is definitely greater than 0.05 mm.

The nature of the distribution of ichnofossils (on both the ventral and dorsal valves of brachiopods) also indicates that boring organisms have populated brachiopod shells after their death. Traces on the samples of the Mining Museum and on samples from Alekseevsky quarry and Dyatlitsy quarry are characterized by endurance in size and shape. Apparently, boring organisms used brachiopod shells as a solid substrate for attachment.
When examining the shells collected in the Alekseevsky quarry under a binocular microscope, isometric-shaped microboring of shells similar to *Trypanites sp* was found.

Although *Trypanites* traces as indicators of the conditions of the hard bottom are described in sufficient detail, *Trypanites* borings in the shells of the Ordovician invertebrates are still extremely poorly studied.

A representative of the genus *Cornulites* Schlotheim, 1820 was discovered by studying the surface of the shell *Porambonites teretior* Eichwald under a binocular microscope (Viivikonna formation (Kukruse regional stage, Lower Sandbian, Uchtna, northeast Estonia).

Two morphologically different types of endobionts were found on the bryozoans *Dianulites petropolitanus*, (the Volkhov river, presumably the collections of R.F. Hecker, the Mining Museum) (Fig. 4):

1. Oval
   a. Oval cigar-shaped
   b. Oval drop-shaped
   c. Convex
2. Spherical

In this list, their position is associated with the hypothetical order of appearance in the bryozoa. Oval convex traces are found on both the upper and lower sides of the colony. They have an oval shape, with strong radial rounding and a significant excess of the length of the major axis over the minor. The length along the major axis is from 27 to 78 mm, and the length along the minor axis is from 6-12 mm. In general, the morphology of traces along the length of the major and minor axis is constant, but it can be seen that at the ends there is a narrowing into a more arrowlike shape. The depth varies from 6 to 18 mm. While it is not constant, it usually has a saddle-like character: deeper at the edges of the trace (15-18) and shallower in the center (6-8 mm). Perhaps this is due to the secondary settlement of these parts. The traces densely cover both sides of this bryozoa, often merge, and form concentric circles with different depths of strokes. They mostly occupy about 70% of the area of bryozoa.
Oval cigar-shaped traces also occur on both the upper and lower sides of the colony. A strong excess of the major axis over the minor axis and the absence of rounding at the end characterize these traces. The length on the long side (major axis) ranges from 10 to 28 mm, while the length on the short side (minor axis) ranges from 2 to 4 mm. Depth is between 1 and 5 mm. They are spread evenly across the surface of the bryozoa and are disparate single-directed single traces which do not merge together. The structural features of the colony of bryozoa do not affect the nature of these traces; the morphology of the traces changes only along the major axis; and the depth and length along the short axis are almost constant. They often populate older and larger traces of different morphology. They occupy about 10% of the bryozoa’s surface.

Oval drop-shapes are also found on different sides of the sample. They are oval, with a slight excess of the major axis over the minor, without rounding, characterized by the most seasoned shape. Sizes range from 14-26 mm on the long side and 4-12 mm on the short side, the depth varies from 10 mm to the through trace of the sample which is about 56 mm, and on average the depth is 15 mm. These traces are located closer to the central part of the bryozoa. The colony morphology does not affect the nature of the traces. In isolated cases the traces are connected, though mainly these are single forms. They occupy about 15% of the sample’s area.

Spherical traces are found only on the underside of the colony. Their diameter ranges from 2 to 6 mm, and their depth is about 4 mm. They are scattered, located closer to the center of bryozoa, do not merge, and occupy about 5% of the sample’s area.

The first group of traces is described by the authors as an oval convex form identical to the traces of Osprioneides described by O. Vinn.

Spherical traces are similar to Trypanites traces, which are common in Ordovician deposits (although mainly in the abiogenic, rather than biogenic substrates). This bryozoa is characterized by a very wide stratigraphic distribution, ranging from the Kunda to the Nabala regional stages (the Darriwilian – the Katian). According to the alleged attribution of this sample to the collection by R.F. Hecker collected on the Volkhov River, this cannot be a stratigraphic level above the Kukruse regional stage (the Sandbian). Thus, this specimen may be indirect evidence of such an early appearance of Osprioneides (before that the first specimens of this species were recorded in the Upper Sandbian deposits of Estonia).

In the stratotype section of the Khrevitsky formation (the Sandbian) on the right bank of the river Khrevitsa near the village Khrevitsa (the sample was found in the crushed limestone), a similar specimen of Dianulites petropolitanus with traces of Petroxestes Wilson et Palmer, 1988 was found. Traces were found on the upper and lateral surfaces of the massive colony.
Dianulites petropolitanus and are represented by longitudinally elongated, not very deep dimples and furrows. The maximum length along the axis is 18 mm, the depth – 2 mm (Fig. 5).

In addition, there is a long (about 12 cm), shallow, curving groove with straightened edges, resembling Maeandropolydora Voigt. This species, regarded as the dominion of polychaete worms, is more characteristic of the Mesozoic and the Cenozoic deposits. The Paleozoic evidence of the discovery of this species is less convincing [14]. In addition, a subisometric shape of a recess is observed on the surface of the bryozoans (diameter up to 2.5 cm, depth about 0.5 cm).

Traces of Arachnostega Bertling were found on many samples of gastropods and cephalopods from various collections of the Ordovician invertebrates of the Mining Museum.

This ichnogenus is common in the Middle and the Upper Ordovician deposits of the Leningrad Region and Estonia [6] and does not have stratigraphic significance. Arachnostega is supposedly most widespread in cold and temperate climates [6]. The exact paleoecology of the ichnogenus is unknown, as is the reason of the formation of traces (traces of habitat or traces of eating). The authors have found numerous traces of Arachnostega on the chiolite’s shells from the above deposits of the Viivikonna formation in Alekseevsky quarry. These deposits were formed in a moderately cold-water sea.

![Fig. 5. Dianulites petropolitanus (Pander) with bioerosion traces](image)

When studying abiogenic disturbances of the surface of fossils from the collections of various authors of the 19th century dedicated to the Ordovician invertebrates of the St. Petersburg and Estland provinces (modern Leningrad region and Estonia), concentric-zonal aggregates of chalcedony and Beekite rings were discovered [15]. In the process of attribution of these collections, it was possible to establish the authorship of some samples, as well as the geographical location (unfortunately approximate). The authors investigated these samples under a binocular microscope and by X-ray microtomography methods and established the dependence of the probability of the appearance and development of these formations from the paleontological substrate. In the Ordovician fossils of eastern Baltoscandia the Beekite rings most actively developed on the shells of the brachiopod suborder Syntrophiidina (genus Porambonites Pander). Beekite rings occur on Porambonites (Porambonites) altus (Pander) (the Volkov regional stage, the Dapingian; Spitham, Estonia), Porambonites teretior Eichwald (the Kukruse regional stage, the Sandbian; Uchtna, Estonia) (Fig. 6), Porambonites (Equirostra) aequirostris Schlotheriam (the Lasnamagi – the Idavere regional stages, the Darriwilian – the Sandbian; central part of the Izhora Plateau).
This suborder is characterized by a microstructure that is favourable to silicification, such as Beekite rings, characterized by a fibrous secondary layer. Organic membranes that contour each calcite crystal of the fibrous secondary layer probably played the key role. An additional factor favourable to the silicification was a peculiar pitted ornament from the Porambonitidae family consisting of thin radial ribs and fairly sharp growth lines. When studying the aggregates under a binocular microscope, one can see that the distribution of Beekite rings on the surface of the shell is controlled by the position of the growth lines. Preservation of the original sculpture of the brachiopod shells, which one may see under the Beekite rings, suggests the hypergene origin of the described spherulites.

Conclusions

The study of invertebrate samples from the collections of the Mining Museum and the authors’ materials revealed the following features:

1. The wide development of a variety of endobionts and epibionts in the studied fossils. Since the bulk of the material was represented by samples from the Sandbian deposits of Leningrad region, one can record an intense moment of the development of epibionts and endobionts during the indicated time in the territory of Leningrad region. This is confirmed by the literature data for western Estonia.

2. The sample of *Dianulites petropolitanus* with traces of *Osprioneides* may be indirect evidence of an early appearance of *Osprioneides* on the territory of Leningrad region (before that the first specimens of this species were recorded in the Upper Sandbian deposits of Estonia).

3. For different stratigraphic levels of the Ordovician deposits of the Leningrad region, several new forms of endobionts were preliminarily established, in particular, a very peculiar shell endobiont belonging to the group of dominions.

4. A study of abiogenic abnormalities in the shells of the Ordovician brachiopods of Baltoscandia revealed a widespread development of so-called Beekite rings. The distribution of Beekite rings on the surface of the brachiopod shells is controlled by the features of the shell’s morphology, namely, the character of the microstructure and sculpture, which, in turn, are diagnostic signs of both large and small taxa. Thus, the appearance of Beekite rings on the surface of fossils is inherent in specific taxa.
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Permian Non-Marine Bivalve Fauna from Continental Deposits of the Dvina-Mezen Basin

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Abstract

Four stages (Urzhumian-Early Severodvinian, Late Severodvinian, Terminal Severodvinian-Early Vyatkian, Late Vyatkian) are established in the evolution of Permian non-marine bivalve fauna from continental deposits of the Dvina-Mezen Basin. The definition of the stages is based on the synthesis of data on the centers of taxon origin, according to their stratigraphic and geographical distribution. It is assumed that disappearance of Angarian non-marine bivalves is correlated to relative warming, as evidenced by the general direction of the positive excursions of carbon and oxygen isotopes on the isotope curves.

Keywords: stratigraphy, non-marine bivalves, Permian, Dvina-Mezen Basin

Introduction

More than 20 non-marine bivalve localities are known from the Middle and Upper Permian continental (lake) deposits of the Dvina-Mezen Basin (north-west part of the East European Platform). The study of fauna from this region began in the middle of the XX century [1], [2], [3], [4], [5], [6], [7]. Meanwhile, non-marine bivalves from the Dvina-Mezen Basin have not been studied recently, and data on them has gradually become outdated. Revision of the systematics of the Permian non-marine bivalves from this area has been performed by the author in 2014-2019 and has made it possible to specify their diversity (41 species, 7 genera, 5 families, 4 super families).

Material and Methodology

The study is based on the collections of non-marine bivalves which are housed in the Geological Museum of Kazan Federal University (coll. no. 36/11). The main collection of non-marine bivalves was collected by the author during field work in the Sukhona and Malaya Severnaya Dvina River Basins in 2013 (Mutovino, Aristovo, Nikulino and Savvatyi Outcrops).

Collections of non-marine bivalves stored in the Geological Museum of Kazan Federal University (GM KFU) and in the Geological Museum of the Geology Institute of Komi Scientific Center, Ural Branch of the Russian Academy of Sciences (Syktyvkar) were also studied.

Remains of non-marine bivalves are represented by shells, internal and composite molds, and imprints. Usually, separate bivalve valves are located parallel or subparallel to the bedding planes.

Revision was carried out by the author using complexes of external, internal, and microstructural features of non-marine bivalves [8], [9], [10]. X-ray computed tomography and scanning electron microscopy were used to study the features of non-marine bivalves.
The definition of the evolutionary stages of different faunal groups, including non-marine bivalves [11], is based on stratigraphic and phylogenetic analysis of their taxa.

The following points have been used in the work: endemic species have ranges belonging to only one paleozoogeographic region, cosmopolitan taxa have ranges belonging to two or more paleozoogeographic regions.

**Results and Discussions**

The synthesis of data on the centers of taxon origin, according to their stratigraphic and geographical distribution, showed that historical events in the development of the Middle and Upper Permian non-marine bivalve fauna from the Dvina-Mezen Basin can be grouped in four stages (Fig. 1) [12].

The **Urzhumian-Early Severodvinian stage** is identified according to the non-marine bivalve localities in the deposits of the Pytyriu Formation (Urzhumian Horizon) and Bezhyudor Formation (the lower half of the Sukhonian Horizon).

This stage is characterized by a small variety of non-marine bivalves’ taxa and by the predominance of Angarian genus Prilukiella (about 67%; 4 species: Prilukiella janischewskyi, Pr. mirabilis, Pr. nitida, Pr. lata). The cosmopolitan subgenus Palaeomutela (Palaeomutela) has a subordinate significance and in the majority of localities includes only small shells of two species (33%): P. (Palaeomutela) vjatkensis, P. (Palaeomutela) extensiva.

The moving in of Prilukiella into the Dvina-Mezen Basin may be due to the cooling observed throughout the East European Platform during the Urzhumian and Early Severodvinian. This cooling is evidenced by the general direction of the negative excursions of oxygen isotopes on the isotope curve observed from the second half of the Late Kazanian to Early Severodvinian [13; Fig. 3].

The **early Severodvinian stage** is identified according to the non-marine bivalves’ localities in the stratigraphic interval from the upper part of the Sukhona Formation (Nyuksenitsa Member; Putyatinnia Horizon, basal part of the Upper Severodvinian Substage) to the Kichuga Member of the Poldarsa Formation (Putyatinnia Horizon, upper part of the Upper Severodvinian Substage).

Angarian species are extremely rare (5.9%; 1 genus, 1 species). They were registered in a very important locality of *Prilukiella janischewskyi*.

In the beginning of this stage the representatives of endemic genus *Opokiella* appears in the Dvina-Mezen Basin (5.9%; 1 genus, 1 species: *Opokiella carinata* Plotnikov). It is possible that these non-marine bivalves moved in this territory from marine basins.

During this stage the isotopic curves of carbon and oxygen isotopes in sedimentary carbonates are characterized by sharp changes in positive and negative values (Fig. 1), which probably indicates frequent climate changes and alternating of warming and cooling.

The terminal Severodvinian-Early Vyatkian stage is identified according to the non-marine bivalves’ localities in the stratigraphic interval from the Kichuga Member of the Poldarsa Formation (upper part of the Upper Severodvinian Substage) to lower part of the Komaritsa Member (Nefyodovian Horizon, Upper Vyatkian substage). Diversity of the non-marine bivalves’ taxa in this stage is at the maximum.

This stage is characterized by the increase of endemic genera (52.4%; 11 species, 4 genera): *Sacmariella sambulacovi*, *S. novoculchumica*, *S. securides*, *Opokiella carinata*, *O. tschernyschewi*, *O. inconcinna*, *O. pakhtusovae*, *O. ignatjevi*, *Verneuilunio plotnikovi*, *V. sp. 1*, *Permania* sp. 1. Simultaneously, the number of species of the cosmopolitan genus *Palaeomutela* decreased. (42.8%; 9 species, 2 subgenera, 1 genus): *P. (Palaeomutela)*

It is assumed that an increase in the number of species of endemic non-marine bivalve genera is correlated to relative cooling, as evidenced by the several close, but short, negative excursions of the oxygen isotope curve from sedimentary and pedogenic carbonates in the interval covering the upper part of the Putyatian and lower half of the Bykovian Horizons. A short positive trend of the carbon isotope curve in paleosol carbonate nodules from the Erga Member (Purtovian Formation) also confirms the relative cooling of the climate (Fig. 1).

The Late Vyatkian stage is identified according to the non-marine bivalves’ localities in the interval corresponding to the larger (upper) part of the Komaritsa Member (Salaryovo Formation, Nefyodovian and Vyaznikian Horizons, Vyatkian Stage).

There are no Angarian species at this stage. Endemics are represented only by the genus Opokiella (38.5%; 5 species, 1 genus): O. tchernyschewi, O. inconcina, O. ignatievi, O. tetraedroides, O. pakhtusovae. The cosmopolitan genus Palaeomutela sensu lato has predominant significance (61.5%; 8 species, 2 subgenera, 1 genus): P. (Palaeomutela) keyserlingi, P. (Palaeomutela) ovalis, P. (Palaeomutela) curiosa, P. (P.) inostranzevi, P. (P.) golubevi, P. (Palaeanodonta) fischeri, P. (Palaeanodonta) parrellela, P. (Palaeanodonta) okensis.

The localities of non-marine bivalves are related to sediments formed at the turn of the Nefyodovian and Vyaznikian. At the end of Nefyodovian a short negative excursion of the oxygen isotope curve and two positive excursions of the carbon isotope curve in sedimentary carbonates were observed. These isotope excursions together indicate a relative cooling of the climate (Fig. 1).

Conclusions

Four stages are established in the evolution of Permian non-marine bivalve fauna from continental deposits of the Dvina-Mezen Basin: the first stage corresponds to the Urzhumian-Early Severodvinian time, the second to the Late Severodvinian time, the third to the Terminal Severodvinian-Early Vyatkian time, and the fourth to the Late Vyatkian time. There are several reasons that affect the biodiversity of the non-marine bivalve fauna: 1) the number of species of the autochthonous cosmopolitan genus Palaeomutela; 2) the moving in and/or extinction of the endemic genera Opokieella, Sacmariella, Verneuilunio, Permianaia; 3) migration of the genera Prilukiella and Concina to the Dvina-Mezen Basin from Angarida.

The migration of the non-marine bivalve fauna from Angarida and the moving in of endemic genera (possible invasion from sea basins) were caused by relative temperature reductions (cooling and humidification), which is confirmed by the data on the oxygen and carbon isotopes curves [14]. The decrease in the diversity of the non-marine bivalve fauna and its extinction is associated with an increase of temperature at the end of the Permian Period. The cooling of the climate occurred at the Permian-Triassic boundary [16], [14], but it could not prevent the extinction of non-marine bivalves in all paleozoogeographical realms.

Acknowledgments

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Using Elastic Parameters for Lithological Description of Sakmarian Sediments (European Russia, Kazan Area)

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Abstract

This paper presents results of the study of elastic parameters of sediments based on core plugs and logging data. The task of lithological differentiation of sulfate-carbonate successions is best solved using the results of acoustic and formation density logging. It has been established that layers of dolomite, anhydrite and gypsum are best suitable for characterization by elastic parameters. The data obtained can be used for interpreting the results of seismic survey and well logging in sulfate-carbonate successions.

Keywords: lithostratigraphy, Sakmarian, well logging, elastic parameters

Introduction

Lithological description of geological sections is one of the main aims of investigations. Core recovery, useful for a clear description of the section, is however not always possible. The implementation of a complex of geophysical methods should allow us to solve this problem. This work focuses on finding a complex of methods for improving the analysis of sulfate-carbonate rocks.

In this paper, the authors propose differentiation of strata based on the use of elastic parameters in order to identify lithological varieties of the Sakmarian stage. This technique is widely applied in the inversion of petrophysical parameters into seismic attributes using well logging for potential assessment of reservoirs [1], [2].

One of the main inversion attributes used in the analysis of seismic data and obtained on the basis of acoustic and formation density logging is the acoustic impedance. Since this parameter is related to the velocity of longitudinal and transverse waves and density, these were the data that have been studied by the authors on core plugs and logging methods.

The study is based on materials from a control well with an expanded set of geophysical methods applied. The core recovery is close to 100%, which allowed us to compile a representative collection of 351 rock samples, in which elastic parameters (longitudinal and transverse velocities and density) were determined. The results obtained were compared with the logging data in order to define the most effective parameters for determining lithological varieties by geophysical methods.

Object of Investigation

The object of study is rocks that make up the geological section of the control well, located on the territory of Kazan (Fig. 1). The section of the well is represented by sediments of the Quaternary, Permian and Carboniferous periods. The Permian system is represented by the Kazanian stage of the Biarmian Series, and the Sakmarian and Asselian stages of the Cisuralian Series. The Carboniferous system is represented by the Gzhelian stage of the Upper...
Carboniferous (Pennsylvanian) Series. According to the lithological description of the full-sized core, deposits of the Sakmarian stage lie in the depth interval from 95 to 180 m and are represented by light-grey dolomites with gypsum interlayers; light-grey anhydrites with a blue tint with dolomite layers; and massive fine-grained gypsum, sometimes with interlayers of anhydrite. The Asselian stage with 30 m thickness is represented by dolomites, mainly with massive texture, with gypsum interlayers in some places. The Gzhelian stage with 90 m thickness is represented by dolomite with nest-like precipitated gypsum in the upper part of the interval and inclusions of organic remains, while cavernosity and clayey matter are increasingly frequently found in the lower part of the section.

**Fig. 1.** Stratigraphy and brief geophysical characterization of the investigated drill core

**Methods**

The research was based on the analysis of the geophysical survey of well logging and core-derived data.

**Well logging data analysis**

Since the investigated drilling is a control one, an expanded set of logging methods was carried out upon it. The complex of electrical logging methods included lateral and micro-lateral logging, induction logging, lateral sonic logging, spontaneous potential, microlog and resistivimetry. Radioactive methods included gamma ray, spectral gamma ray, formation density, neutron-gamma and neutron porosity. In addition, caliper logs, curves of nuclear magnetic and acoustic logs, as well as thermometry, were recorded in the well.

To assess the lithology of the Sakmarian sediments [3] and the elastic rock parameters in the section studied, formation density curves and acoustic logs were selected out of the whole range of methods.

The determination of elastic parameters along the core was based on the results of MPAL cross-dipole acoustic logging studies. One of the stages of processing the results was the calculation of transverse and longitudinal wave travel velocities. For a comprehensive
assessment of all waves in a wave packet, the semblance method [4], [5] was used, which has proven well-suitable. As a result of processing the initial wave pattern data, the interval time curves of the longitudinal and transverse waves were obtained, which were then converted into velocity curves. Density along the section was estimated using formation density logging equipment. Thus, longitudinal and transverse wave velocities, as well as rock density, were deduced as a result of processing and analysing the well log data.

**Core data analysis**

For laboratory studies of the rocks, cylindrical core samples with 30 mm diameter and 70 mm length were selected. A total of 351 samples were examined. As all samples were of regular cylindrical shape, the density of the sample was calculated by measuring its mass and volume [6].

The dynamic characteristics of rocks on core samples were determined by the pulse method [7]. This method is based on direct measurement of the propagation time of a sound pulse through a sample from the emitter to the receiver. The acoustic parameters (longitudinal and transverse wave velocities) on the core were determined using the PIK-UZ-UEP device (fabricated by Geologika, Novosibirsk). The source generates a signal with a frequency of 1 MHz. The full wave pattern of the acoustic pulse passing through the sample is recorded. In this wave pattern, the time of arrival of the wave is registered and wave travel velocity in the sample is calculated.

**Results**

The results of measuring the density of core samples were compared with the results of formation density logging. As we can see from Figure 2, the results of density logging are in good agreement with the core data (the correlation coefficient turned out to be 0.76). A general analysis of the data shows increased densities obtained from well logging data, which is caused by the measurement conditions, since core samples were not saturated before the study.

**Fig. 2.** Comparison of results of core studies with well logging data: VP – longitudinal velocity; VS – transverse velocity, RHOB – gamma-gamma density logging data

In the comparison of core and logging velocity data, the correlation coefficient was 0.52 for longitudinal waves and 0.5 for transverse waves. In general, velocity values obtained from core samples are slightly higher compared to the velocities measured in the well. This may be due
to the measurement conditions, in particular, to the difference in the frequencies of the well and laboratory equipment.

Data from both core and formation density logging show a variation in the average density values in rocks from the Sakmarian part of the drilling: in gypsum – 2.28-2.49 g/cm$^3$, in dolomite – 2.52-2.58 g/cm$^3$, in anhydrite – 2.83-2.87 g/cm$^3$. Thus, the lithotypes are clearly differentiated based on the density parameter with only small overlaps and have close boundaries in the core and well logs.

**Discussion**

Analysis of the acoustic and density characteristics of the Sakmarian deposits was based on three-dimensional cross-plotting. Fig. 3 shows cross-plots based on geophysical investigations and core data. The density values are color-coded. A zonal distribution of the longitudinal and transverse wave velocities can be observed. However, there is no clear differentiation of lithotypes, when comparing both logging and core data.

Fig. 3. Characterization of Sakmarian sediments by the parameters Vp, Vs, and density based on well logging (a) and core (b) data. Light-blue dots – gypsum, brown dots – dolomite, dark-blue dots – anhydrite

To obtain denser bonds by acoustic parameters, the values of P-impedance (IP) and S-impedance (IS) were calculated [8].

Analysis of cross-plots in Fig. 4 shows that all three lithological varieties are well differentiated in the space of elastic parameters. Log and core data lie within the same boundaries. It can be claimed that the selected parameters can be used for lithological differentiation.

Lithological columns (Fig. 5) have been compiled based on data derived from the IP and IS well logging curves (LITH_Log) as well as on the core description (LITH_core). As can be seen in the figure, a layer interpreted as a dolomite stratum occurs in a depth interval of 162.3-162.8 m, within a 160-165 m deep anhydrite stratum, according to the logging data. This interval corresponds to anhydrite deposits with dolomite interlayers, evidenced by the lithological description. Similar deviations throughout the studied interval correlate either with transition zones or with less pure lithological varieties. The method presented is good in identifying purer lithologies.
Fig. 4. Lithological differentiation by acoustic impedance and density parameters: a, b – VS-IS distribution cross-plots based on logging data (a) and core data (b); c, d – VP-IP distribution cross-plots based on logging data (c) and core data (d).

Table: Properties of borehole samples

<table>
<thead>
<tr>
<th>GR</th>
<th>DEPT</th>
<th>Core_Vp</th>
<th>Core_Vs</th>
<th>LITH_Log</th>
<th>Core_Density, g/cc</th>
<th>LITH_cor</th>
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</thead>
<tbody>
<tr>
<td>mcR/h</td>
<td>m</td>
<td>2500</td>
<td>7500</td>
<td>4500</td>
<td>1.5</td>
<td>3.5</td>
</tr>
<tr>
<td>NGR</td>
<td></td>
<td>100</td>
<td>1500</td>
<td>4500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ue</td>
<td>5</td>
<td>150</td>
<td>4500</td>
<td>1.5</td>
<td>3.5</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5. Synthesis and interpretation of core sample and logging data

Conclusion

Acoustic and density methods were selected from the complex of logging methods applied to a control drilling as most sensitive to lithology changes within a sulfate-carbonate succession. Use of acoustic impedance values made it possible to increase the reliability of lithotyping (dolomite, anhydrite, and gypsum). The lithological columns obtained from the core description and from the results of processing the logging data are quite similar to each other, with the exception of transition zones and zones of interbedded lithotypes in the array of another. The data obtained can be used for interpreting seismic and well logging results in sulfate-carbonate sections.
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The Use of Modelling Acoustic Properties to Study the Porosity of Carbonate Rocks on Core Samples

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Abstract

The aim of this work is to quantify the pore space features of carbonate rocks according to petrophysical studies (using the pore aspect ratio - PAR) and to classify the pore space of carbonates according to the results of microscopic studies. The integration of laboratory measurements of 97 carbonate samples and petrographic analysis of 10 samples allowed the acoustic signature of pore types to be quantified. Three rock groups have been identified, which differ in a number of lithological, petrophysical, and acoustic properties. The main criterion for separation was the pore aspect ratio, which does not depend on porosity and velocity, but on the shape of the pore space.

Keywords: Carbonate rock, petrophysical study, acoustic property, elastic property, rock physics model, pore aspect ratio, laboratory measurement

Introduction

The study of reservoir properties of sedimentary deposits is very relevant both to the engineering practice of developing hydrocarbon deposits, and to the fundamental understanding of sedimentary basins [1]. Reservoir property studies are of particular importance to the rational development of mineral resources in the Republic of Tatarstan (Russia), where up to 38% of recoverable oil reserves are concentrated in carbonate rocks [2].

The aim of this work is to quantify the pore space features of carbonate rocks according to petrophysical studies (using the pore aspect ratio – PAR) and to classify the pore space of carbonates according to the results of microscopic studies.

In this paper, attention is focused on a comprehensive study of the pore space features of carbonate rocks. The use of acoustic properties for studying porosity on core samples is described in sufficient detail in the works of Fournier et al., [1], [3], [4]. The results of these studies show that in carbonate rocks, the dispersion of acoustic properties exists and is due to the shape of the pore space [3] and the presence of micro porosity (pore size less than 30 microns), which is not determined by optical-mineralogical studies. [5].

One of the main problems of the study of pore space of carbonate rocks is a wide variety of pore types. In this regard, the pore space should be classified taking into account the structural features of rocks and their petrophysical properties [6]. A detailed classification of porosity was proposed by Choquette and Prey in 1970 [7]. It is based on the genesis of pore space and is not related to the petrophysical properties of rocks. A more modern classification of the pore space of carbonate rocks, which takes into account petrophysical properties, was proposed by Jerry Lucia [5]. Using the results of laboratory studies of porosity, permeability and capillary properties, as well as the description of the rock matrix, Lucia divided the pore space into two main types: interparticle and vuggy porosity. Vuggy porosity, in turn, is divided into two classes depending on the interconnectedness of the pores: 1) separate-vug pores: isolated pores connected only by interparticle pores; 2) touching-vug pores: interconnected pores connected
by means of channels and voids. This raises the second problem considered in this paper: the correct classification of carbonate rocks, to take into account both structural and textural features and petrophysical elastic properties. In order to improve the quality and accuracy of typing the pore space, the PAR (pore aspect ratio) is introduced, which allows the pores to be quantitatively divided into different types, taking into account the physical properties of the whole rock.

**Methodology**

Core samples were taken from three wells located on the southern slope of the South Tatar Arch. The samples are confined to Lower Carboniferous rocks (82 samples) and the Upper Devonian rocks (15 samples).

The whole complex of laboratory studies included:
1. Sample preparation (drilling of cylindrical samples with a diameter of 30 mm on the “BUR MT-131” machine).
2. Extraction of cylindrical core samples.
   To separate cylindrical core samples from the oil and bitumen contained in them, the Soxhlet apparatus was used. An alcohol-benzene mixture was used as a solvent. The extraction was considered to be complete when a reagent of transparent colour, containing no hydrocarbons, left the sample.
3. Determination of porosity.
   The porosity was measured using the gas-volumetric method based on the Boyle-Mariotte law: gas volumes and pressure are changed in the system, and particle volume and porosity are calculated from the obtained data. The porosity parameters were measured on the “Plast-215.”
4. Determination of the mineral composition of the studied samples on an X-ray diffractometer.
   X-ray fluorescence analysis (XRF) is one of the modern spectroscopic methods for studying substances. The objective of the method is to study the elemental composition of the samples.
   The X-ray powder diffraction method is based on the collection and subsequent analysis of the spectrum arising from the irradiation of the test material with x-ray radiation. X-ray fluorescence analysis was performed on an “S8 Tiger” wave dispersive X-ray fluorescence spectrometer (Bruker, Germany). The specified equipment allows the elemental composition of solid, powder and liquid samples in the range from B to U in a vacuum or helium atmosphere, to be determined.
5. Study of the acoustic properties of core samples in model reservoir conditions.
   Ultrasonic measurements were conducted using the “PIK-UZ-UEP” equipment (“Geologika”). The system consists of two ultrasonic heads, a signal source and an oscilloscope.
   Velocities were calculated from the sample length and the measured one-way transit time of the waves along the sample axis. Velocities were measured under hydrostatic (reservoir) conditions, at confining pressure 20 MPa.
   A more detailed study of the pore space involved analysing the acoustic properties compared to rock physics models. A quantitative measure of the pore shape in rock physics models [4], [9] is the pore aspect ratio (α) (PAR). Using the assumption of an ellipsoidal pore shape, the PAR parameter is the ratio of the short radius of the ellipse to its long radius, and varies in the range from 0 (cracks) to 1 (pores of a spherical shape). It is important that the PAR parameter is a simplified (model) method for describing the shape of pores, which relates the petrophysical properties of the rock and its structural and textural features. Rock physics methods evaluate the pore aspect ratio (α) with known data on the mineral composition of rocks, porosity, and longitudinal and shear wave velocities. Using a limited collection of core samples for
modelling, it is possible to quantitatively describe the relationship between acoustic velocity and rock porosity depending on the shape of the pore space.

Based on the results of laboratory studies, the values of porosity, mineralogical composition, and ultrasonic velocities were determined. Next, from every ninth sample (total 10), thin sections were made for optical microscopic studies. The criterion for choosing the “control” samples was their acoustic properties (the 10 selected samples cover the entire range of P and S wave velocities). The lithological description of the thin sections allows us to classify the available samples not only by their physical parameters, but also by their texture, and the pore features.

Results

The results of the petrophysical studies were used in modelling the theory of effective media. Rock physics modelling used the Power Log software product, in the Rock Physics Module (CGG Geosoftware). For modelling, we used the differential effective medium (DEM) theory [9], [10]. The differential effective medium (DEM) theory models two-phase composites by incrementally adding inclusions of one phase to the matrix phase. Moreover, the pores must be of a certain shape, which is described using the PAR parameter. The pore aspect ratio was quantified; it ranged from 0.012 to 0.2. The results of petrophysical studies and modelling of rock physics are presented in fig. 1. The results of comprehensive studies (petrophysical and lithological-petrographic) are presented in table 1.

Based on the results of the generalization of petrophysical and petrographic data, three rock groups were identified:

- **Group 1.** Rocks with fracturing, cracks are almost completely filled with calcite. PAR is less than 0.07. Mudstone. Indicated by blue circles on the graph (Fig. 1).
- **Group 2.** Samples are dominated by microporosity and interparticle porosity. Pore aspect ratio is from 0.07 to 0.12. Samples are presented by wackestone. Red rhombs (Fig. 1).
- **Group 3.** Macro and mesopores of intraparticle pore type predominate in the samples. Pore aspect ratio is generally in a range from 0.12 to 0.2. According to the results of studying thin sections of the “control” samples, this group is packstone. Green squares (Fig. 1).

![Fig. 1. Porosity versus P-wave velocity for all samples](image-url)
Table 1. Results of petrophysical studies and petrographic description of thin sections

<table>
<thead>
<tr>
<th>Lithofacies type</th>
<th>α</th>
<th>ϕ, %</th>
<th>Vp, m/s</th>
<th>Group</th>
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<tr>
<td>mudstone</td>
<td>0.011</td>
<td>0.74</td>
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<td>packstone</td>
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</table>

Discussion

As can be seen from Figure 1, the acoustic properties of carbonate rocks have a high degree of dispersion. Therefore, it is impossible to very accurately predict the porosity of the sample from the velocities of S and P waves. So, for example, if the P-wave velocity is 5200 m/s, the porosity varies from 1 to 10%. Conversely, if the porosity is 10%, the P-wave velocity values range from 4250 to 5500 m/s. This is primarily due to the complex structure of the pore space in the rock. It leads to a need for new tools in the analysis of elastic and reservoir properties of carbonates. In this case, such a tool is a rock physics modelling.

Verification of modelling, which is carried out using lithological research, is also necessary. The results of studying thin sections of “control” samples confirm the correct separation of the pore space of carbonates according to their physical properties and further rock physics modelling.

Conclusions

As a result of this work, 97 core samples were investigated. Porosity varies from 0.73 to 18.45%. The P-wave velocity varies from 3987 to 6462 m/s, S-waves: from 1889 to 3347 m/s.

An analysis of laboratory experiments showed that the elastic parameters of the samples are highly dispersed. Therefore, the rock physics was modelled to quantify the shape of the pore space using the PAR parameter (pore aspect ratio). This parameter ranges from 0.012 to 0.2.

Also, a “control” group consisting of 10 core samples was identified. Thin sections were made from this group, and optical microscopic studies were performed. This group consists of the following lithogenetic types: Mudstone, with a fracture, almost completely filled with calcite; wackestone, with a predominance of microporosity and interparticle porosity; packstone, with the presence of macro- and mesopores and moldic porosity.

Three rock groups have been identified, which differ in a number of lithological, petrophysical, and acoustic properties. The main criterion for separation was the pore aspect ratio, which does not depend on porosity and velocity, but on the shape of the pore space. One of the methods of rock physics modelling was tested—it was the differential effective medium theory. This method can be used to reduce uncertainty in the field of dependence of porosity and elastic properties, not only in the framework of laboratory studies, but also at the scale of the well, using logging data supported by petrophysical and petrographic laboratory studies.

Modelling results are a reliable basis for both seismic inversion and geomechanical modelling, for establishment of a reliable relationship between dynamic and static elastic parameters.
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Early Cretaceous Microbiofacies and Paleobathymetry in the Eastern Russian Platform

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Abstract

The paleobathymetric modelling of the Early Cretaceous sedimentary basin in the Eastern Russian Platform was undertaken on the basis of habitat specificity of benthic foraminifers identified in the Lower Cretaceous mudrocks from the Tatar Shatrashany borehole. It is found that calcareous benthic foraminifers (Lagenida, Nodozariida, Polymorphinida, and Rotaliida) inhabited the entire shelf. Increasing emergence of new calcareous species marks basin deepening up to the base of the neritic zone. It was the best tool of paleobathymetric interpretation that calcareous forms dissapeared on the boundary of shelf and upper bathyal zone. The agglutinated forms such as Lituolida, Trochamminida, Astrorhizida, Textulariida, Ataxophragmiida, and Ammodiscida populated deeper parts of the basin from lower neritic to upper bathyal zone where they were abundant. The generic and species diversity of calcareous and agglutinating community, the emergence of new species, the total population of foraminifers were calculated. A quantitative paleobathymetric curve was constructed based on these parameters and biofacial zonation. It characterizes depth variation in the basin in the late Hauterivian – Middle Albian.

Keywords: benthic foraminifers, calcareous forms, agglutinated forms, bathymetry, Cretaceous, Russian Platform

Introduction

In the Early Cretaceous, the eastern part of the Russian Platform was covered by an epeiric sea that was also a strait between the north-eastern Peri-Tethys and the Boreal-Arctic Sea [1].

The Uljanovsk-Saratov Trough is one of the largest synclises of the eastern Russian Platform, it stretches in the eastern part of this platform for ~850 km being filled with Middle-Late Jurassic, Cretaceous, and Paleogene deposits.

The stratigraphical framework of the Lower Cretaceous deposits of the Uljanovsk-Saratov Trough was proposed by Sazonova and Sazonov [2] and then slightly updated by further works [3], [4]. During the last 70 years, a comprehensive litho-, bio-, and magnetostratigraphic study of numerous boreholes and outcrops has been undertaken [5], [6], [7]. Despite the detailed lithological and biostratigraphical knowledge on the Lower Cretaceous deposits of study area, there are a few articles on benthic foraminifers (BF) in the basin and no articles on quantitative paleodepth reconstructions. Noteworthy, BF assemblages may be successfully used as a reliable paleobathymetric tool based on their bathymetric habitat specificity and numerical treatment of the association. This article is aimed to fill this gap using the Lower Cretaceous BF assemblages from the Tatar-Shatrashany borehole (The Volga River right side, Sura-Sviyaga interfluve).
Paleobathymetric reconstructions in the Early Cretaceous sedimentary basin and quantitative micropaleontologic assemblage analysis were undertaken on the basis of general palaeobathymetric model of BF habitats in the study area [5], [8] (Fig. 1). The water depth model is based on the Berggren’s [9] bathymetric zonation indicating that various calcareous BF groups such as Lagenida, Nodozariida, Polymorphinida, and Rotaliida inhabited principally the entire shelf while some calcareous BF strongly impoverished along transition from neritic to upper bathyal zone. Agglutinated forms such as Lituolida, Trochamminida, Astrorhizida, Textulariida, Ataxophragmiida, and Ammodiscida typically dominated in deeper parts of the basin, i.e. from lower neritic to upper bathyal zones.

Fig. 1. Model of paleobathymetric habitats of major groups of BF in the Early Cretaceous epeiric sea in the North-Eastern Peri-Tethys (modified after [8])

BF assemblage analysis resulted in the palaeobathymetric curve, which can be employed in reconstruction of regional sea-level changes and basin evolution.

**BF Assemblages and Water Depth Estimations**

Microfaunal analysis revealed rich BF assemblages in the Lower Cretaceous part of the Tatar-Shatrasingh borehole section (Fig. 2). Distribution of BF in the study section resulted in BF zonation which in conjunction with the ammonite zonation makes possible to provide a reliable correlation of the strata with a chronostratigraphic scheme [10]. Noteworthy, BF were not found in the bituminous shales of the Uljanovsk Fm corresponding to Early Aptian Oceanic Anoxic Event 1a [7], [11], [12] (Fig. 2).

According to the general palaeobathymetric model of habitats of BF in the study area [8] (Fig. 1), percentages of selected calcareous and agglutinating species were calculated. Thus, palaeobathymetric zonation and the palaeobathymetric curve result from variation of these parameters along the section (Fig. 3).

As it was concluded, the Lower Cretaceous strata were formed in a quite deep basin. The Upper Hauterivian – Middle Aptian mudrocks were accumulated in the lower neritic and upper bathyal zones. The basin depth varied slightly around 200 m and remained constant in general.
Fig. 2. Distribution of BF in the Lower Cretaceous deposits from the Tatar-Shatrasheany Borehole

Legend: 1 - sandstones; 2 - mud rocks; 3 - bituminous shales; 4 - distribution of BF in the section: a - first occurrence; semi-quantitative representation of foraminifers in the sample; b - single (1-5); c - rarely (6-10); d - common (11-15); e - abundant (more than 15); 5 - dominant calcareous benthic foraminifers; 6 - dominant agglutinated foraminifers

Fig. 3. Quantitative distribution of BF in the Lower Cretaceous strata, paleobathymetric zones, and paleobathymetric curve. For the Legend, see Fig. 2
The most significant deepening (350 m) coincided with the Upper Hauterivian Simbirskites decheni ammonite zone followed by relative depth stabilization without significant variations. The Lower Aptian bituminous sediments were formed in the upper bathyal zone, with an estimated water depth around 250 m. The middle Albian mudrocks are thought to be accumulated in deeper basin in comparison to that of underlying Lower Aptian rocks. The basal Albian strata were deposited in lower neritic zone. Then, the basin deepened to upper bathyal zone with a maximum depth (~350 m) interpreted for the lower part of the Middle Albian part of the section.

Conclusion

The results from the analysis of quantitative parameters calculated for the Early Cretaceous assemblage of benthic foraminifers and the paleoecological features of calcareous and agglutinated forms allowed us to estimate variations in paleodepth and to construct the paleobathymetric curve. In the Early Cretaceous, the eastern part of the Russian Platform was covered by an epeiric sea, with a depth of 100-200 m, shallowed periodically to almost 50 m and deepened the Late Hauterivian and middle Albian to a depth of 350 m.

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Volcanogenic Influx into the Epeiric Sea of the Russian Platform

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Abstract

The “camouflaged” pyroclastics composed of smectite, illite-smectite, and zeolite, in association with volcanic glass fragments was found in the Upper Jurassic – Lower Cretaceous strata of the northeastern Peri-Tethys (eastern Russian Platform). Variations in pyroclastic matter distribution are regarded to be associated with fluctuations in volcanic influxes into the study area. The Armavir basalt stratovolcano is among the main sources of volcanic ash clouds transported the pyroclastic material to the basin. In the middle Albian, the volcanic activity is thought to be the most intense, and pyroclastics from the Ciscaucasian backarc basin, including that from the Armavir Massif, was supplemented by ash clouds transported from the Crimean volcanic arc.

Keywords: pyroclastics, mudrocks, black shales, upper Jurassic, lower Cretaceous, Russian Platform

Introduction

Layers with “camouflaged” pyroclastic material, which are evidence of ash cloud unloading, are found in the both modern and ancient deposits of the eastern Russian Platform. Volcanic material found in the Upper Jurassic rocks from the eastern Russian Platform was firstly reported by [1]. In studied thin-sections from the lower and middle Volgian marlstones and bituminous shales, the authors found volcanic ash particles with gas inclusions in association with sharp crystals of pyroxene, amphibole, and biotite.

It was recently revealed [2] that significant amounts of montmorillonite, albite, microcline, and diopside was identified in the lower Aptian bituminous shales corresponding to the Oceanic Anoxic Event 1a (OAE-1a), which allowed to propose significant influx of pyroclastic material into the sea in the early Aptian from the Ciscaucasian volcanic zone.

As there are few articles on mineral composition of the Upper Jurassic-Lower Cretaceous rocks from the north-eastern Peri-Tethys (eastern Russian Platform), the features of their origin are not studied thoroughly, and the present article aims at filling this gap and shedding light on the origin of these rocks. Taking into account that studied succession is composed mostly of mudrocks interbedded by the black shales, it is of great importance to provide such an investigation as these rocks contain a variety of mineral resources [3].

Geologic Setting and Lithostratigraphy

30 core samples of mudrocks and black shales from the Tatar-Shatrashany borehole were studied by the XRD and electron microscopic analyses to address the discussed problem. The Tatar-Shatrashany borehole is located in the north-eastern Peri-Tethys, within the Uljanovsk-Saratov Trough (Fig. 1).

The Upper Jurassic strata consist of bluish gray and light gray carbonate mudrocks and marlstones, up to 25 m in thickness (upper Kimmeridgian Novikov Formation (Fm) and Lower-mid Volgian Trazov Fm), dark brown and greenish brown bituminous shales, 6-8 m in thickness
(mid Volgian Promzino Fm), and greenish gray sandstones, with phosphorite pebbles, 0-1.5 m in thickness (upper Volgian Undor Fm) (Fig. 2).

The Lower Cretaceous (upper Hauterivian-mid Aptian and mid-Albian) deposits are dark gray, mostly carbonate-free mudrocks, with rare interlayers of quartz sandstones. Maximum thickness of the upper Hauterivian (Klimov Fm) is more than 60 m, that of the Barremian (Uren Fm) is more than 40 m, that of the lower-mid Aptian (Khmelev, Uljanovsk, Studenets, and Zarykley Fms) is about 90 m, and that of the mid-Albian (Alov Fm) is up to 130 m. Importantly, the lower Aptian deposits include bituminous shales (Uljanovsk Fm), 3 to 9 m in thickness (Fig. 2) reported to correlate with OAE-1a [2], [4].

Mineral composition and microfabrics

The XRD analysis allows quantitative mineral composition of rocks (Fig. 2). According to the SEM analysis, the brownish gray bituminous shales from Upper Jurassic Promzino Fm contain clusters of board-like heulandite crystals (Fig. 3 a), dense pyrite framboïds (Fig. 3 b), flaky pyrite-bearing montmorillonite aggregates, and disintegrated pyrite framboïds (Fig. 3 b).
Fig. 2. Lithology, TOC, and mineral composition of the rocks from the Tatar-Shatashany section. Pink dashed hatch marks the “camouflaged” pyroclastic matter.

The Lower Cretaceous strata consist of dark gray mudrocks mostly constituted of flaky aggregates typical for montmorillonite and illite, lamellar aggregates of chlorite and kaolinite, and scattered fragments of volcanic glass (Fig. 3 c).

The organic carbon-rich strata corresponding to the OAE-1a (Uljanovsk Fm) consist of homogeneous dense flaky aggregate of montmorillonite (Fig. 3 d) with rare plant particles and densed pyrite framboinds of about 8 μm in size. Noteworthy, mudrocks from the mid-Albian Alov Fm are characterized by the highest content of montmorillonite (44%), illite-smectite (13%), and zeolite (15%) (Fig. 2). These contain unaltered sharp particles of volcanic glass and board-like clinoptilolite crystals (Fig. 3 e).

Discussion

Commonly, volcanic eruptions are accompanied by strong ash falls, which have much stronger influence on the geological environment than it is usually thought. Ash clouds are reported to move over more than 4500 km from the volcano due to strong stratospheric air flows which could transport them on a very long distance and even turn around the Earth [5].
Fig. 3. SEM images and energy-dispersive spectra of the Upper Jurassic and Lower Cretaceous rocks from the Tatar-Shatrashany section. A, B - bituminous shale from the Mid-Volgian Promzino Fm; C - mudstone from the Lower Aptian Khmelev Fm; D - bituminous shale from the Lower Aptian Uljanovsk Fm; E - mudstone from the Mid-Albian Alov Fm. Cln – clinoptilolite, Heu – heulandite, Mnt – montmorillonite, Pyr – pyrite, Gl – volcanic glass, Pla – plant particle.

Discharge of ash clouds and precipitation of glass particles in the marine basin are followed by immediate diagenetic alteration of unstable ash particles and their transformation to more stable mineral components, mostly known as “camouflaged” pyroclastics. This material comprises smectite, zeolite, opal-CT, and glauconite, in association with the semi-dissolved or fresh volcanic glass fragments, from which this association is formed [6], [7], [8], [9].

Previously, it was concluded [2], [10] that the middle Volgian Promzino and lower Aptian Uljanovsk organic carbon-rich strata are proposed to have been affected by significant
volcanogenic influx due to high amount of “camouflaged” pyroclastic matter revealed in black shales. The XRD and SEM analyses applied to the Upper Jurassic – Lower Cretaceous succession from the Tatar-Shatrashany section including both organic carbon-high and organic carbon-low strata prove strongly the idea on the permanent influx of volcanic matter into the study basin (Fig. 2). Variations of montmorillonite, mixed layer illite/smectite, and zeolite considered to be derived from alteration of volcanic ash [11] are regarded to be associated with fluctuations in volcanic influxes on the study area during the late Jurassic-early Cretaceous.

Fig. 2 shows constant occurrence of pyroclastics in mineral composition of the studied rocks. The Upper Jurassic strata contain ~20% pyroclastics in the Trazov marlstones increasing dramatically to more than 50% in the Promzino black shales. The Lower Cretaceous Klimov-Khmelev and Zarykley mudrocks consist of ~40% pyroclastic matter, whereas the OAE-1a-related Uljanovsk black shales and overlaying Studenets mudrocks contain ~50% of pyroclastics. The highest amount of volcanogenic input (more than 70%) is found in the Alov mudrocks, evidencing the volcanic matter as the major contributor for the mid-Albian sediments in north-eastern Peri-Tethys.

Among possible sources of the pyroclastics delivered to the basin, the Armavir basalt massif could be proposed [12], [13] being located almost 1000 km to the south from the study area. It is reported to form and to erupt in the Late Jurassic-Early Cretaceous during the activity of the Ciscaucasian backarc volcanism (Northern Caucasus), and this event is represented by basalt and diorite lavas and pyroclastic flows, more than 500 m in thickness [13]. The last strong eruptive phase of this long-lived stratovolcano is recorded to take place in the Albian. That is why the Alov mudrocks contain the highest values of montmorillonite (44%) and zeolite (15%), which in conjunction with unaltered particles of volcanic glass makes possible to propose a complex influx of a pyroclastic material into the basin, probably moved not only from the Atmavir stratovolcano, but additionally from the Crimean volcanic arc that was in its active phase in the Albian as well [14].

Conclusions

1. The Upper Jurassic-Lower Cretaceous succession from the north-eastern Peri-Tethys (eastern Russian Platform) was accumulated under strong input of the pyroclastic material, which was altered partly or completely, with formation of new minerals such as smectite, zeolite, and mixed-layered minerals.
2. The content of pyroclastics in the Upper Jurassic Trazov marlstones is ~20%, it increases dramatically to more than 50% in the Promzino black shales. The Lower Cretaceous Klimov-Khmelev and Zarykley mudrocks comprise of ~40% pyroclastic matter, whereas the OAE-1a-related Uljanovsk black shales and overlaying Students mudrocks contain ~50% pyroclastics. The highest amount of volcanogenic input (more than 70%) is found in the middle Albian Alov mudrocks.
3. Variations in pyroclastic matter values in the studied section are regarded to be associated with fluctuations in volcanic influxes in the north-eastern Peri-Tethys during the Late Jurassic-Early Cretaceous. The Armavir basaltic stratovolcano could be proposed among the main sources of the volcanic ash clouds that transported pyroclastic material to the basin. In the middle Albian, the volcanic activity is thought to be the most intense, as the pyroclastics from the Ciscaucasian backarc basin, including that from the Armavir Massif, was supplemented by ash clouds from the Crimean volcanic arc.
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Element Geochemistry of the Organic Carbon-Rich Strata from the North-eastern Peri-Tethys

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Abstract

Geochemical observations of two black shale beds corresponding to the Late Jurassic Oceanic anoxic event (OAE) and early Aptian OAE-1a from the Kimmeridgian-Albian succession representing the epeiric basin of the north-eastern Peri-Tethys are provided to estimate influences of different processes and conditions related to their accumulation. Total organic carbon content and organic carbon isotope ratio variations reveal terrigenous rather than marine source of the organic matter accumulated during the OAE-1a in the basin. Strong near-surface weathering affected the upper Jurassic black shales during the subsequent long-term erosion. Values of redox-sensitive parameters reveal almost synchronous vertical distribution marking black shales beds by clear positive shifts being much higher than those in host marlstones and mudrocks. The organic carbon-rich Promzino and Uljanovsk black shales were deposited under predominantly anoxic to euxinic bottom-water conditions, whereas the organic carbon-poor intervals of the Upper Jurassic-Lower Cretaceous Formations were deposited under oxic-suboxic conditions. Evidenced by Mo/TOC values, strong watermass restriction probably caused by the late Jurassic eustatic fall and consequent basin shallowing is proposed during for the Late Jurassic OAE. In contrast, the watermass restriction during the OAE-1a was less strong, and the basin definitely had more or less strong connections with the Tethys Ocean.

Keywords: OAE, black shales, redox conditions, geochemistry, upper Jurassic, lower Cretaceous, Russian Platform, Peri-Tethys

Introduction

The Late Jurassic-Early Cretaceous transition was a critical interval in the Earth history marked by large-scale volcanic activity and greenhouse conditions, extremely high sea level, rather low ocean circulation, and frequent anoxia in epeiric seas and on ocean margins [1].

Black shales formed mostly in anoxic conditions have long been in focus of study, not only because of their potential as hydrocarbon source rocks but also due to their important role in paleoenvironment reconstructions. The latter are of a very high importance in understanding biogeochemical changes in modern basins and providing reliable forecasts for possible consequences of that.

Considering the Oceanic anoxic events (OAEs) are interpreted as a “black shales factory” that worked under conditions of a short-term severe stagnation and stratification of water masses, decrease in dissolved oxygen in the water, and conditions under which organic matter (OM) resist in sediments, the Late Jurassic OAE and the Early Aptian OAE-1a [2] could cause massive environmental changes from the pre- to the post-event evolution of the epeiric basin in the north-eastern Peri-Tethys.
In order to better understand anoxic paleoenvironments in the northern hemisphere in context of the quick and sudden OAEs, geochemical investigations were carried out to study the Upper Jurassic-Lower Cretaceous succession of the eastern Russian Platform containing two black shale formations (fms), namely the middle Volgian (upper Tithonian) Promzino Fm corresponding to the upper Jurassic OAE and the lower Aptian Uljanovsk Fm corresponding to the OAE-1a [3], [4]. The both strata are traditionally considered to be classical examples of the “preservation” endmember reflecting deposition in a stagnant, euxinic basin [1], [5] (Fig. 1).

Thus, geochemical observations of the two above-mentioned black shales and the host strata of Kimmeridgian-Albian age were made and then combined with the previously published data to estimate influences of different processes in the basin.

![Location of studied area: a – on the Tithonian-Berriasian paleogeographic map (simplified from [1]), b – on the Early Aptian paleogeographic map (simplified from [1])](image)

A total of 29 bulk-rock core samples of the Upper Jurassic-Lower Cretaceous marlstones, black shales, and carbonate-free mudrocks from the Tatar-Shatrashany borehole section were studied aiming geochemical peculiar features investigating.

Major and trace element analyses were carried out at the Institute of Geology and Petroleum Technologies of Kazan Federal University (Kazan, Russia). Concentrations of trace elements were measured using an inductively coupled plasma mass spectrometer iCAP Qc (ThermoFisher Scientific, Germany). Major elemental composition was investigated using the S8 Tiger X-ray fluorescence wave-dispersion spectrometer (Bruker, Germany). Total organic carbon (TOC) content was determined at the Geonauka Centre for collective use at the Institute of Geology of Komi Science Center of Ural Branch of Russian of Academy of Sciences (Syktyvkar, Russia) using an AH-7529 analyzer.

**Total Organic Carbon Content and Organic Carbon Isotopy**

Variations in the $\delta^{13}$C of organic matter ($\delta^{13}$C$_{org}$) are usually interpreted in the terms of changes in contribution by terrigenous and marine organic carbon to basins due to changes in productivity and atmospheric pCO$_2$ levels [6]. Terrigenous OM is usually identified by lower $\delta^{13}$C values due to higher content of light carbon isotope in terrestrial plant particles.

The stratigraphically lowest Upper Jurassic Novikov and Trazov marlstones display low TOC content (0.6-0.8%) and relatively low organic carbon isotope ratio values (-25 / -26.6‰) (Fig. 2). The overlying Promzino Fm is characterized by the highest content of TOC (8.4-27.3%) and higher organic carbon isotope ratio (-23.4 / -25.9‰). The mudrocks from the Lower Cretaceous Klimov, Uren, Khmelev, Studenets, and Albian Alov Fms are characterized by low
and relatively constant TOC values that range from 0.3% to 1.5%. The δ\textsuperscript{13}C\textsubscript{org} values vary between -23.8 and -27.8‰. The lower Aptian Uljanovsk Fm corresponding to the OAE-1a displays relatively low TOC content in the concretion limestones (1.3%) and high TOC values in the bituminous shales (6.1-10%).

![Fig. 2. Stratigraphic variations of redox proxies for the Tatar-Shattrashany section. Brown areas correspond to the organic carbon-rich intervals.](image)

The organic carbon isotope ratio values determined in the Uljanovsk black shales are the lowest in the section (-28.8 / -29.4‰). This result evidences for higher terrigenous OM influx during the deposition of the OAE-1a – related Uljanovsk Fm than that in the mid-Volgian when the Promzino Fm deposited.

Sackett and Thompson [7] reported the preferential removal of isotopically light carbon during oxidation leads to enrichment in \textsuperscript{13}C in the residual bulk organic matter; similar processes could be responsible for the observed negative isotopic shift in organic carbon-rich OAE-1a-related Uljanovsk Fm. In contrast, the Upper Jurassic Promzino black shales show elevated δ\textsuperscript{13}C\textsubscript{org} values in comparison to both Uljanovsk bituminous shales and host mudrocks. This result can be related to strong near-surface weathering affected the Promzino strata during the widespread Late Jurassic- Early Cretaceous erosion.

According to [8], destruction of aromatic hydrocarbons during weathering is usually accompanied by preferential loss of compounds that are structures enriched in the \textsuperscript{12}C isotope. Interestingly, a positive shift to -23.4‰ revealed in Promzino Fm is associated with the highest TOC value (27.2%) in the studied succession.

**Trace Elements Redox Proxies and their Interpretation**

Regarding anoxic basins are widely thought to act as a trap for stable sulfide-forming trace metals (TM), specific TM must be located within the sediments rather than in the water column.

Several trace elements are enriched in reducing sediments, and these are highly sensitive to redox changes making them and their ratios important proxies for paleoredox reconstruction [9].
The U/Th ratio is among geochemical proxies commonly used as an indicator of redox conditions due to different behaviour of U and Th in terms of solubility. The ratio of U/Th higher than 1.25 marks an anoxic environment, and its values of 0.75-1.25 signal suboxic to dysoxic environment, while a ratio lower than 0.75 indicates oxic environment [9]. The Promzino and Uljanovsk bituminous shales are deposited in reducing environments of good preservation conditions having values in 2.1 and 1.4-2.6 range, respectively, while the host marlstones and mudrocks are deposited in oxic conditions as implied by values in 0.1-0.5 range of the U/Th ratio (Fig. 2).

Wignall and Myers [10] proposed the authigenic uranium content as an index of bottom water anoxia in ancient sedimentary sequences, expressed as \( U_{\text{au}} = U - \text{Th}/3 \). The \( U_{\text{au}} \) content higher than 12.0 indicates anoxic conditions and that of 5.0–12.0 indicates suboxic to dysoxic conditions, while the \( U_{\text{au}} \) content lower than 5.0 indicates oxic conditions [9]. The results mark mostly oxic conditions in which the host marlstones and mudrocks are deposited (-2.4/-2.7). The Promzino bituminous shales are formed in strongly dysoxic conditions (11.1-11.9), while the Uljanovsk bituminous strata are deposited in different redox conditions, varied episodically from dysoxia to euxinia (5.7-17.8) (Fig. 2).

As trace element concentrations of marine sediment represent mixtures of both detrital and authigenic components, it is mostly the concentrations of authigenic components that vary in response to redox changes in the water column. In order to minimize the effects of weathering and post-depositional alteration, the trace element concentrations were normalized to Al contents. Both organic carbon-rich formations display distinct, but high V/Al, U/Al, and Mo/Al ratios indicating reducing conditions, whereas organic carbon-low strata show low values of these ratios marking oxic conditions in the basin (Fig. 2).

Mo is among TM, which are widely used to determine anoxic conditions due to the fact that under oxic conditions, seawater Mo mostly exists in the form of unreactive molybdate oxyanion, whereas under sulfidic-anoxic conditions, Mo is readily transferred to sediment by adsorption onto organic matter and other Fe-bearing particulates [11].

Considering black shales are usually enriched in Mo, the amount of Mo transferred to sediment in anoxic marine environments is dependent upon both the concentrations of sedimentary organic matter and the degree of watermass restriction. Therefore, Mo/TOC ratios can be used to assess the degree of basin restriction resulted from loss of contact with open sea basins [12].

Bituminous shales from the Promzino and Uljanovsk Fms show considerable Mo and Mo/TOC enrichment (Figs 2, 3), with Promzino shales having Mo values in the 22-24 ppm range, whereas the Uljanovsk shales have higher values, some in excess of 140 ppm. Lowest Mo concentrations (5.7 ppm or less) occur in the organic carbon-low Novikov and Trazov marlstones and the Klimov-Alov mudrocks. The Mo/TOC ratios of the Uljanovsk shales are of the highest values varying from 10.3 to 41.6 (20 in average), whereas the Promzino shales display much lower values in 0.8-2.9 range (1.8 in average) (Figs 2, 3).

These results allow to suppose the Late Jurassic anoxic basin in the eastern Peri-Tethys was much more restricted than that in the early Aptian, and it was even more restricted comparing with modern Black sea (Mo/TOC ratio is 4.5) [12]. In contrast, the watermass restriction during deposition of the OAE-1a-related Uljanovsk black shales is thought to be less strong than that in the late Jurassic being quite similar to that of the modern Cariaco Basin (Mo/TOC ratio is 25) (Fig. 3).
Fig. 3. Plot of Mo versus TOC for Promzino and Uljanovsk black shales and host rocks of the eastern Russian Platform. Mo-TOC modern environments are given in [12]). Legend: 1-2 – Studenets-Alov, 3 – Uljanovsk, 4 – Klimov-Khmelev, 5 – Promzino, 6 – Novikov.

Host organic carbon-low rocks have low Mo/TOC ratio values, the Lower Cretaceous mudrocks show Mo/TOC values in 0.4-3.1 range, the Upper Jurassic marlstones display 3-9.1 range (8 in average) (Fig. 3). Values of Mo and Mo/TOC are low due to their deposition under suboxic conditions, and, therefore, Mo/TOC ratios in the organic-poor intervals are not useful for evaluation of the degree of basin restriction.

Discussion

The OAE is generally interpreted as a set of sedimentary, geochemical and biological events [2], the related black shales may record massive changes from the pre- to the post-OAE environments in the north-eastern Peri-Tethys.

The TOC content and the organic carbon isotope ratio variations in the Kimmeridgian-Albian succession distinctly point on two organic carbon-rich intervals presented by the Upper Jurassic (middle Volgian) Promzino Fm and the lower Aptian Uljanovsk Fm corresponding to the upper Jurassic OAE and early Aptian OAE-1a, respectively [2]. The data obtained indicate on predominance of terrigenous rather than marine source of the OM accumulated during the OAE-1a and strong near-surface weathering affected the Promzino strata during the widespread latest Jurassic-earliest Cretaceous erosion on the study area.

All measured redox-sensitive parameters show almost synchronous vertical distribution marking black shale beds by clear positive shifts higher than those in the host marlstones and mudrocks (Fig. 2). Thus, redox condition played a crucial role in OM accumulation during deposition of both black shale beds. The organic-rich intervals of the Promzino and Uljanovsk Fms were deposited under predominantly anoxic to euxinic bottom-water conditions, whereas the organic-poor intervals were deposited under oxic-suboxic conditions.

Strong watermass restriction is proposed during accumulation of the Upper Jurassic OAE-related Promzino black shales. Probably, it was caused by the Late Jurassic eustatic fall [13] and consequent basin shallowing [14], and, therefore, connections between the observed basin and the northern and southern open seas were weakened. In contrast, the watermass restriction during deposition of the OAE-1a-related Uljanovsk black shales was less strong, and the basin definitely had more or less distinct connections with the Tethys Ocean. This is evidenced by the Mo/TOC values; diminished oxygenation together with enhanced water column stratification, promoted anoxic conditions favourable for the preservation of OM.
Conclusions

1. The TOC content and the organic carbon isotope ratio variations in the Kimmeridgian-Albian succession of the north-eastern Peri-Tethys distinctively point on two organic carbon-rich intervals corresponding to the upper Jurassic OAE and early Aptian OAE-1a.

2. A terrigenous rather than marine source of the OM dominated during the OAE-1a in the basin.

3. Strong near-surface weathering affected the Promzino strata during the widespread latest Jurassic-earliest Cretaceous erosion in observed area.

4. Values of redox-sensitive parameters reveal almost synchronous vertical distribution marking black shales beds by clear positive shifts, much higher than those in the host marlstones and mudrocks.

5. The organic carbon-rich intervals of the Promzino and Uljanovsk Fms were deposited under predominantly anoxic to euxinic bottom-water conditions, whereas the organic carbon-poor intervals were deposited under oxic-suboxic conditions.

6. Evidenced by Mo/TOC values, strong watermass restriction probably caused by the Late Jurassic eustatic fall and consequent basin shallowing is proposed for the Late Jurassic OAE. In contrast, the watermass restriction during the OAE-1a was less strong, and the basin definitely had more or less distinct connections with the Tethys Ocean.

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