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# Organic matter, its generation potential, and the composition of the Artinskian deposits of the north of the Pre-Ural Foredeep (Timan-Pechora Province)

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This article discusses the results of lithological and geochemical studies of the Artinskian deposits and organic matter, which is a part of the petroleum source rocks of the northern part of the Pre-Ural Foredeep of the Timan-Pechora Province. The rocks are very diverse in composition (clastolites, pelitolites, carbonatolites and mixtolites) and structural and textural features. Mixtoliths are widespread in shallow-marine environments (lower molasse deposits), which are associated with mixed terrestrial and marine organic matter. We recorded the predominance of poor and fair petroleum source rocks due to increasing terrigenous component. Mixtoliths of the Kochmes area (HI of 240 mg HC/g TOC) are characterized by the best generation potential. Organic petrography studies indicate the predominance of bituminite (sapropel base) in the composition of organic matter, the terrigenous components dominates in the eastern regions adjacent to the Urals.

**Keywords:** *Pre-Ural foredeep, artinskian deposits, mixtoliths, petroleum source rocks, organic matter, bituminite, generation potential.*

# Органическое вещество, его генерационный потенциал и состав артинских отложений севера Предуральского краевого прогиба (Тимано-Печорская провинция)

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Проведено литолого-геохимическое исследование артинских отложений и органического вещества, входящего в состав нефтегазоматеринских пород северной части Предуральского краевого прогиба Тимано-Печорской провинции. Породы очень разнообразны по составу (кластолиты, пелитолиты, карбонатолиты и микстолиты) и структурно-текстурным особенностям. В мелководно-морских обстановках (нижнемолассовые отложения) широко распространены микстолиты, с которыми связано смешанное гумусово-сапропелевое органическое вещество. Отмечается преобладание бедных и средних нефтегазоматеринских пород за счет увеличения гумусовой составляющей. Наилучшими генерационными показателями характеризуются микстолиты Кочмесской площади (HI – 240 мг УВ/г $C_{орг}$). Углепетрографические исследования указывают на преобладание битуминита (сапропелевая основа) в составе органического вещества, гумусовая составляющая доминирует в восточных районах, примыкающих к Уралу.

**Ключевые слова:** *Предуральский краевой прогиб, артинские отложения, микстолиты, нефтематеринские породы, органическое вещество, битуминит, генерационный потенциал.*

## Introduction

Currently, the problems of oil and gas bearing potential of foredeeps are relevant all over the world [1, 4, 5]. The studies of petroleum source rocks, assessment of their generation potential, transformation of organic matter (OM), characteristics of the lithological-facies features of petroleum source rocks and enclosing strata are carried out. Trough zones of fold-thrust areas in various regions of the world (Zagros fold system (Iran, Iraq), basins of Maturin (Venezuela), Chaco (Bolivia, Argentina), Llanos (Colombia), Tarim (China)) are among the largest areas in terms of oil and gas production [1, 3, 4].

The northern part of the Pre-Ural Foredeep and the adjacent areas of the western slope of the Urals are among the promising areas for prospecting and exploration for oil and gas in the Timan-Pechora province [9, 13]. Geological exploration surveys carried out here in recent years have discovered new oil deposits (Nersetinskoe), gas deposits (Levogrubeyuskoe) and new hydrocarbon deposits at known oilfields (Intinskoe) [9]. Limited knowledge of deep drilling and a complex tectonic structure are the main factors that restrain the active involvement of the territory in the exploration process. These negative factors also include poorly developed models of the structure and formation of promising sedimentary formations. The issues of depositional settings and facies modeling for this area are covered mainly in large generalizations for the Pechora Basin [8, 15]. Results of a comprehensive study of oil and gas content issues (source rock and enclosing strata estimates) of the Pre-Ural Foredeep are published [6, 7, 15]. One of the promising oil and gas bearing strata are Artinskian terrigenous deposits, which are part of the Permian (Upper

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Paleozoic) oil and gas complex. They are widespread in the north of the Pre-Ural Foredeep and are quite thick. This paper deals with the composition and structure of the Artinskian rocks, the hydrocarbon potential as well as considers the type OM of the petroleum source rocks.

## Objects and research methods

The study area is located within the Pre-Ural Foredeep: the Chernyshev Ridge, Kosyu-Rogovaya and Korotaikha Depressions. In total, the following nine well sections were studied: South-Stepkovozhskaya-1, Khosedayu-Neruyuskaya-6, Povarnitskaya-21, Bergantymylkskaya-1,3, Kochmesskaya-1,3, Middle-Kochmesskaya-2, Palnikshorskaya-1, and 2 outcrops along the Kozhim and Silovayaha rivers. The lithological and geochemical studies included the optical-microscopic method, complete chemical silicate analysis (wet), silicate X-ray fluorescence analysis and diffractometric analysis of clays. Petroleum source rocks were investigated by organic petrography as well as by organic geochemistry methods: organic carbon determination — $C_{org}$, %; chloroform bitumoid — A-CBA, %; gas-liquid chromatography of the aliphatic fraction — GLC (Syktyvkar); Rock-Eval pyrolysis (Moscow, VNIGNI).

## Results and discussion
## Material composition of the rocks

The Artinskian rocks are represented by clastolites, pelitolites, carbonatolites and mixtolites (rocks of mixed composition), formed in deep-water and shallow-water marine environments [6, 14]. In the east of the study area in the north of the Pre-Ural Foredeep, a deep-sea depression filled with terrigenous flysch sediments was formed in the Artinskian age. During the Artinskian stage, carbonate sedimentation continued in shallow-water shelf environment along the strike in a westerly direction, within the Kochmes area [8]. In the Late Artinskian – Early Kungurian time, terrigenous and terrigenous-carbonate deposits of the lower molasse accumulated everywhere in shallow-sea environments. The investigated well sections are represented mainly by coastal-marine sediments of the lower molasse; terrigenous flysch sediments were studied along the outcrops of the Kozhim and Silovayaha rivers. Artinskian molasse deposits are represented by a thin alternation of layers of predominantly mixed siliceous-terrigenous and carbonate compositions. The total thickness of the Artinskian deposits is greatest in the central parts of the Kosyu-Rogov Depression. The maximum thickness of flysch sediments is 1.5 km (increasing eastward), and the maximum thickness of gray-colored marine molasse is up to 3 km [6]. Assessment of the distribution of source rocks in the Artinskian complex, according to the data of average gamma-activity (well logging), showed that their greatest thickness is confined to the southern and southeastern parts of the Kosyu-Rogov Depression.

Artinskian rocks are diverse in composition as well as in structural and textural features. Table 1 shows brief characteristics of some types of rocks in the studied sections (Bergantymylkskaya, Padimeyskaya, Kochmesskaya, Povarnitskaya, Khosedayu-Neruyuskaya areas), which on the modular diagram [16] GM (hydrolyzate module) — $Na_2O + K_2O$ (sum of alkalis) (Fig. 1, f) form 5 clusters (clusters No. I, II, III, IV, V). Outside the clusters, there are relatively clean carbonatolites (Povarnitskaya and Khosedayu-Neruyuskaya areas).

## Organic matter composition and its hydrocarbon potential

Contemporary $C_{org}$ (TOC) contents in clayey rocks of flysch deposits vary from 0.7% (Silovayaha River) to 3.7 % (Kozhim River), and has the range of 0.5–3.8 % in mudstones of terrigenous and terrigenous-carbonate molasses. According to organic petrography and geochemical studies, the OM contains producers of terrestrial and marine material (Fig. 2, a–c). In general, a zone with a similar mixed composition of OM (terrestrial and marine), which differs in the proportion of terrigenous components, is recognized in the Artinskian deposits. The lateral change in geochemical parameters occurs due to the catagenetic transformations of OM from the southern part of the Kosyu-Rogovaya depression to the northeast of the Korotaikha Depression.

Rock-eval data indicate a change in the values of the hydrogen index (HI, mg HC/g TOC) in a wide range from the first tens to 240 (Fig. 2, h). The decrease in the generation rate is due to a large proportion of terrigenous detrite. Higher HI values — 215–240 mg HC/g TOC were found in shallow-water shelf mixtoliths and carbonatolites of the Kochmes area (clusters I — III), where the proportion of terrigenous components in OM is reduced and prevails the bituminite, a structureless marine type substance (Fig. 2).

In comparison with the entire Permian terrigenous complex on the studied territory, the Artinskian deposits, which contain predominantly marine OM, have an initially higher hydrocarbon (oil) potential. The Kungurian coal-bearing strata generally have a low hydrocarbon potential [11, 12]. Increased values are only noted in local areas of the northern regions (Vorkutsky), where the proportion of liptinite components in the OM increases [10–12]. The total assessment of the possible hydrocarbon generation of an oil character will be significantly higher in the Artinskian complex than in the coal-bearing one due to the predominance of type I–II of the initial OM and catagenetic transformation sufficient for fluid generation.

According to the published data, the catagenetic transformation of the OM of the Artinskian deposits increases towards the Ural folded structure. The maturity of OM varies from gradations of $MC_1$–$MC_2$ on the western side of the Kosyu-Rogov Depression to gradations $AC_{1-2}$ on its eastern side and in the Korotaikha Depression [6]. The organic petrography and Rock-eval data carried out indicate the unfinished generation of hydrocarbons in the Artinskian deposits of the Kochmesskaya, Khosedayu-Neruyuskaya, Bergantymylkskaya, Padimeyskaya and South-Stepkovozhskaya areas, where these deposits have not yet left the oil window zone (catagenesis gradation, $MC_2$).

In the indicated areas, in various types of rocks the active release of bitumen (Bit) from bituminite ($L_{bit}$) is very clearly visible (Fig. 2, d, e). In the zone of higher maturity (Ro > 0.85 %, $MC_3$ gradation) in the Kozhimskaya and Middle-Kochmesskaya areas, bituminous smears and excretions from OM are not observed, bituminite has a residual appearance, and the bulk of the rock is represented by terrigenous detrite (vitrinite and inertinite Fig. 2, d, f, g). The main generation of hydrocarbons from the Artinskian formations source rocks within the eastern part

**Table 1.** The main types of Artinskian rocks in the north of the Pre-Ural Foredeep

**Таблица 1.** Основные типы артинских пород севера Предуральского краевого прогиба

| Cluster (Fig. 1, f) / area<br>Кластер / площадь | Composition of lithological rock types<br>Состав литологических типов пород | Composition of rock-forming components<br>Состав породообразующих компонентов |
|---|---|---|
| I<br>Kochmesskaya, Povarnitskaya, Khosedayu-Neruyuskaya | Bioclastic (spicular) limestones, silicified, with abundant silty-sandy admixture, bioturbated (carbonate-siliceous-clayey in various ratios),<br>Fig. 1, a–c | Carbonate component (11–55 %): calcite bioclastic (up to 70 %) — sponge spicules (60–90 %), crinoids, bryozoans, ostracods, brachiopods, foraminifera; micro-grained and pelitomorphic calcite (rarely dolomite?). Traces of the vital activity of organisms (bioturbation) are 10–25 %, composed of pelitomorphic calcite and dolomite (?). The terrigenous fine-grained component (15–40 %) consists of fragments of quartz, albite, and potassium feldspar; glauconite, muscovite, leucoxene, and iron hydroxides and pyrite are less common. The siliceous component (10–35 %) is newly formed quartz (usually in the form of chalcedony). |
| II<br>Kochmesskaya | Carbonate silty sandy mudstone with sliding micro-folds | The predominant part of the rock (about 55–60 %) is of micro-grained-pelitomorphic texture of clay, siliceous and carbonate compositions. Clay material with characteristic aggregate extinction. The clastic component estimated at 40–45 % of the total rock is represented by quartz and silty-sandy feldspars (from 0.02 mm to 0.10 mm). The silty sandy material is distributed over the thin section in lenticular interlayers. There can be found remnants of sponge spicules of siliceous and calcareous compositions as well as rare fragments of ostracod valves. Abundant formations of diagenetic pyrite are observed in some areas of the thin section. |
| III<br>Kochmesskaya, Padimeyskaya | Finely interbedded silty sandstones and silty mudstones with a clay-siliceous binding mass (Padimey), with a carbonate admixture and traces of bioturbation (Kochmesskaya),<br>Fig. 1, d, e | The rocks have a fine-cyclite (3–10 mm) structure, a sharp bottom, sometimes with subsidence microstructure. The clastic part (up to 40–60 %) is represented by quartz, feldspars (acidic) and single rock fragments, with an abundance of terrestrial OM in bedding. The cementing matrix (40–60 %) is of quartz-feldspar or clay-chlorite composition with micro-grained quartz or carbonate admixture (fragments of sponge spicules, ostracods). |
| IV<br>Berghantymylkskaya, Padimeyskaya | Graywacke sandstone, fine-grained, poorly sorted, with varying degrees of roundness and film-porous (carbonate (up to 30 %) and clayey-silty matrix (10 %). | The structure is massive, the texture is from silty to sandy (medium-grained), with a predominance of a fine-grained (0.10–0.25 mm) component. The roundness of the clastic part is predominantly 1–2 points. Clastic part (70–90 %) — quartz, potassium feldspar, plagioclase, chlorite, biotite, muscovite, iron oxides and hydroxides; rock fragments – silicites, effusive rocks of different composition, granitoids, indeterminate chloritized rocks. |
| V<br>Povarnitskaya | Slightly sandy siltstones with a carbonate-siliceous-clayey matrix, thin-layered, with an abundance of detrite terrestrial and marine OM | The structure is thin-layered. The clastic part is fine-grained (0.03–0.1 mm) – quartz, feldspar, and there also can be found lenticular formations of cryptocrystalline quartz (neoplasms?). Carbonate component (40–65 %): calcite bioclastic (up to 60 %) — ostracods, foraminifera, brachiopods, bryozoans, crinoids and spherulites; pelitomorphic calcite. Cement is carbonate-siliceous-clayey. Detrite of mixed terrigenous and marine composition with separate inclusions of macrospores (transferred) is well diagnosed among the OM components. |
| Outside the cluster Povarnitskaya, Khosedayu-Neruyuskaya | Limestones (floutstones according to Dunham [2]) with terrigenous silty-sand admixture, with silicification and rarely dolomitization (rhombohedrons) | Carbonate component (40–65 %): calcite bioclastic (up to 60 %) — crinoids, bryozoans, sponge spicules, ostracods, brachiopods, fusulinides; pelitomorphic calcite (rarely dolomite?) up to 40 %. Terrigenous component (17 %) — fragments of feldspar and quartz with a predominance of the latter. Siliceous matter (5–10 %) — newly formed cryptocrystalline quartz replaces the shells and cavities of bryozoans and fusulinids. There are also crinoid segments replaced by glauconite; pyrite is ubiquitous, it is framboidal and forms large crystals (up to 1.2 mm). |

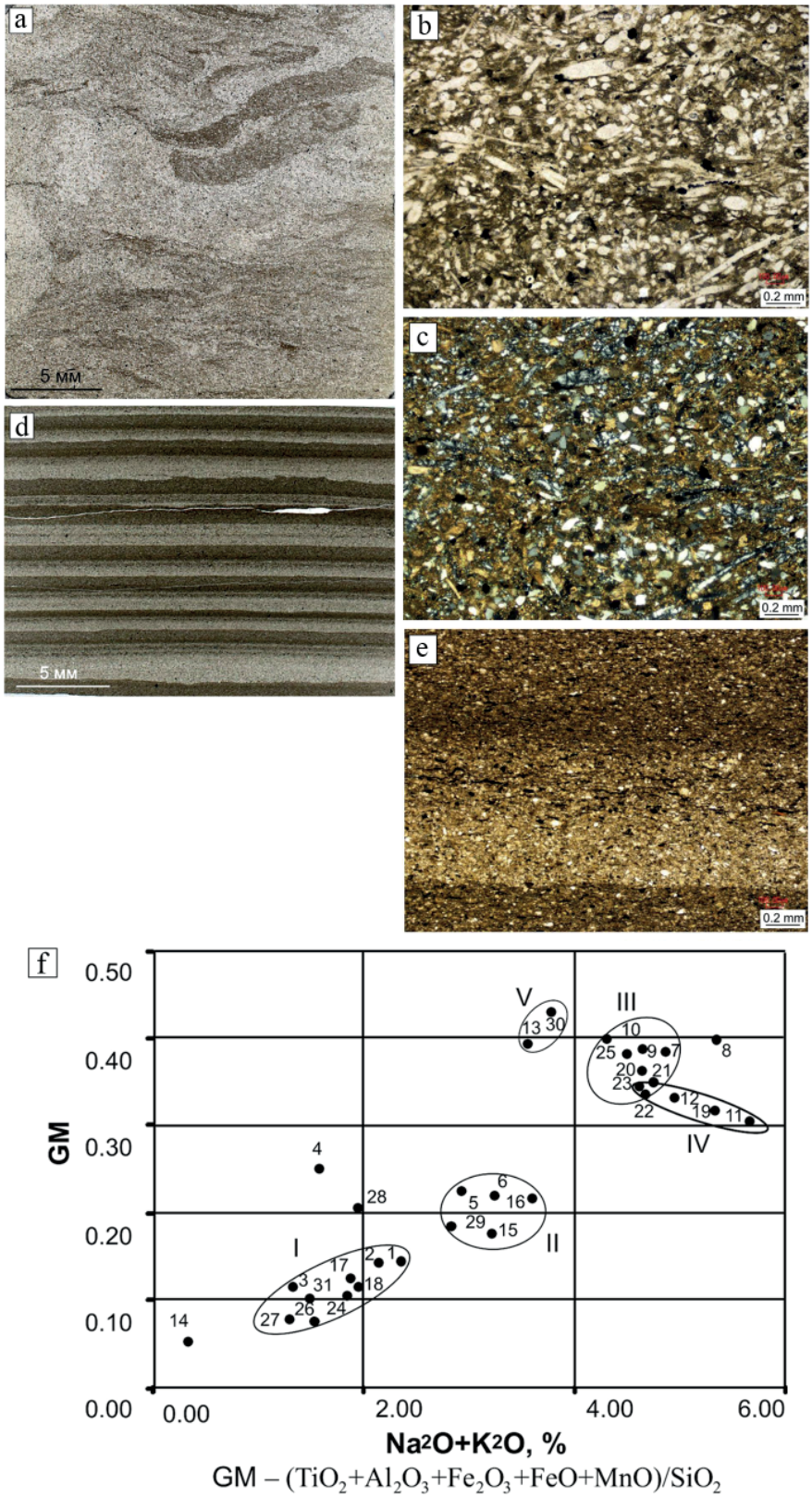


**Fig. 1.** Some rock types from the Artinskian sequences of the Kosyu-Rogovaya Depression; a–c — Kochmesskaya-3 well, depth 1522.4 m, sample 9/1; a — silicified spicular limestone with clay-silty-sandy admixture (scanned thin section); b — detail (a), thin section without analyzer; c — with an analyzer; d–e — Padimeyskaya-1 well , depth 1415.5 m, sample 4/2; d — thin cyclites of siltstones and mudstones with gradational bedding (scanned thin section); e — detail (d), thin section without analyzer; f — modular diagram: hydrolyzate module (GM) — sum of alkalis ($Na_2O + K_2O$) according to [16]

**Рис. 1.** Некоторые типы пород из артинских последовательностей Косью-Роговской впадины: a–c — скв. Кочмесская-3, гл. 1522.4 м, обр. 9/1; a — спикуловый известняк окремнелый с глинисто-алевро-песчаной примесью (сканированный шлиф), b — деталь (a), шлиф без анализатора; c — с анализатором; d, e — скв. Падимейская-1, гл. 1415.5 м, обр. 4/2; d– тонкие циклиты алевролитов и аргиллитов с градационной слоистостью (сканированный шлиф), e — деталь (d), шлиф без анализатора; f — модульная диаграмма: гидролизатный модуль (GM) — сумма щелочей ($Na_2O + K_2O$) по [16]

of the Kosyu-Rogov Depression has been completed. The latter is confirmed by the level of OM maturity and the earlier estimate of the generation time by petroleum source rocks of the Pre-Ural Foredeep [6].

## Conclusions

The Artinskian rocks of the north of the Pre-Ural Foredeep are very diverse in composition and structural and textural features. A wide distribution of shallow-marine mixtoliths was revealed in the lower molasse, in which a mixed terrestrial and marine OM predominates. It was established the presence of poor and fair petroleum source rocks, the hydrogen index varies from a few tens to 240 mg HC/g TOC. A decrease in the generation rate occurs due to a large proportion of terrigenous detrite in the OM. The highest HI values, 240 mg HC/g TOC, were found in the mixtoliths of the Kochmesskaya area, where bituminite (marine components) predominates in the OM.

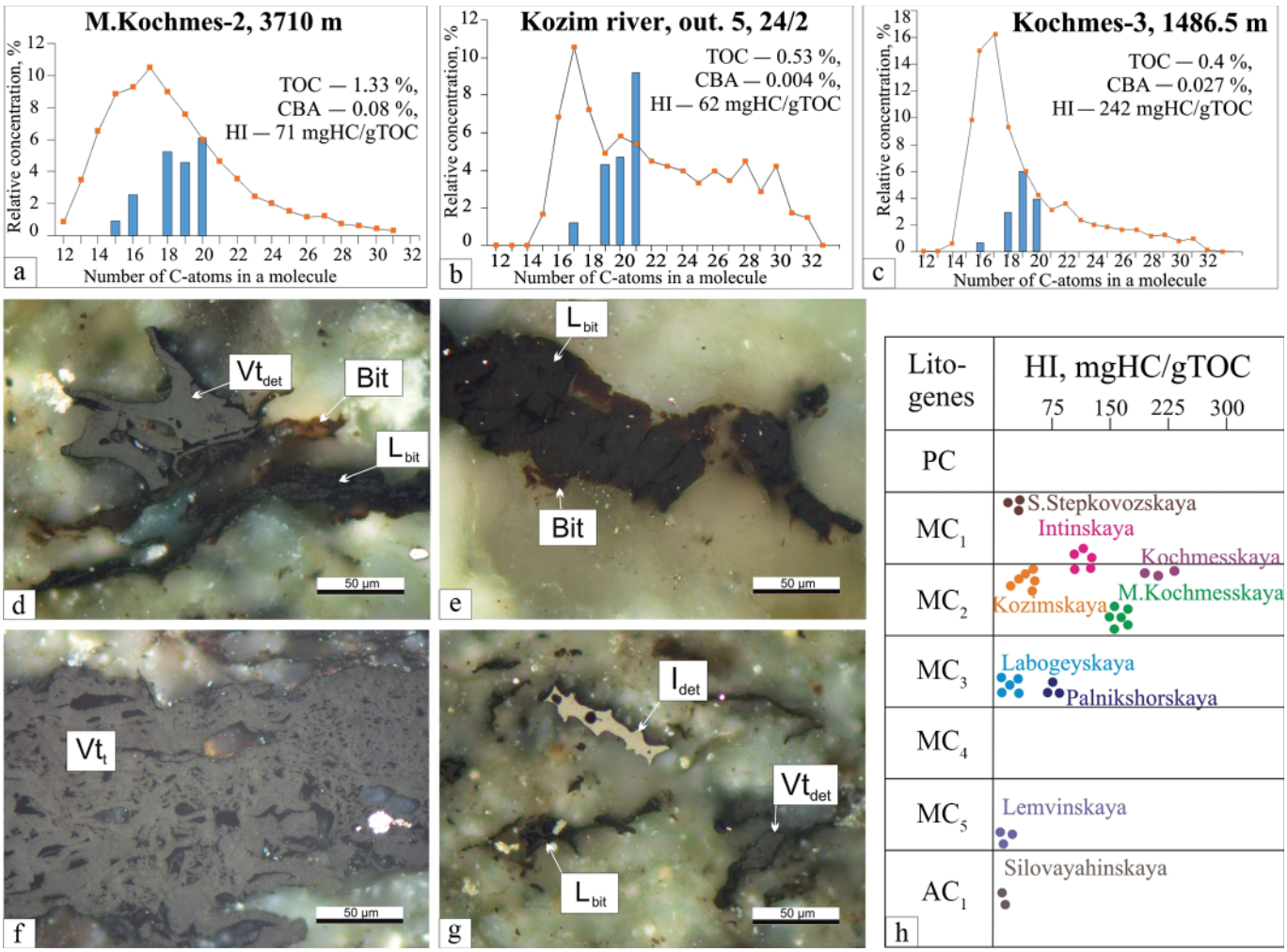


**Fig. 2.** Histograms of normal and isoprenoid alkanes (a–c) distribution, examples of organic matter inclusions (d–g) and changes in the hydrogen index (h — HI) in $P_1$ar rocks (d –Bergantymylkskaya-1 well, depth of 2000.1 m, sample 5-1a; e — Padimeyskaya-1 well, depth 1402.1 m, sample 2-2; f — Padimeyskaya-1 well, depth 1415.2 m, sample 4-4; g — Padimeyskaya-1 well, depth 1414.9 m, sample 4-1; polished sections, reflected light, oil immersion, ×50. $L_{bit}$ _ bituminite (liptinite group); $Vt_t$ — telinite, $Vt_{det}$ — vitrodetrinite (vitrinite group); $I_{det}$ — inertodetrinite (inertinite group); Bit — bitumen. Compiled with additions for [6]

**Рис. 2.** Гистограммы распределения нормальных и изопреноидных алканов (a — c), примеры включений органического вещества (d–g) и изменение водородного индекса (h — HI) в породах $P_1$ar (d — скв. Бергантымылькская-1, гл. 2000.1 м, обр. 5-1a; e — скв. Падимейская-1, гл. 1402.1 м, обр. 2-2; f — скв. Падимейская-1, гл. 1415.2 м, обр. 4-4; g — скв. Падимейская-1, гл. 1414.9 м, обр. 4-1; аншлифы, белый свет, масляная иммерсия, ув. ×50. $L_{bit}$ — битуминит (группа липтинита); $Vt_t$ — телинит, $Vt_{det}$ — витродетринит (группа витринита); $I_{det}$ — инертодетринит (группа инертинита); Bit — битум. Составлен с дополнением по [6]

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