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# Facies models of the Achimov formation of East-Urengoyskoe license as the basis for optimizing exploration and field development patterns

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**Abstract**. The results of sedimentological core analysis of the Achimov formation (Upper Valanginian, Lower Cretaceous) confirm that it was formed by higher efficiency systems of submarine fans in (relatively) deep marine basin. Lithofacies models of $Ach_{5-6}$ were generated, well correlation was performed based on the comprehensive analysis of core, well logging and seismic data. Distributary channels and proximal parts of depositional lobes are characterized by the best reservoir properties.

**Keywords**: the Achimov formation, facies, turbidities, submarine fan, permeability

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## Introduction

The East-Urengoyskoe license is located in the northern part of Western Siberia in the Nadym-Pur petroleum region, tectonically associated with Urengoy mega-arch. According to the stratigraphic zonation of Nothern Siberian Berriasian-Aptian deposits, the area under study is located in Urengoy-Purpe lithofacies area, Urengoy subarea (Decision of the 6th Interdepartmental Stratigraphic Meeting…, 1991). Achimov formation ($Ach_{5-6}$) of early Valanginian time ($K_1v_1$) conformably overlays the Bazhenov formation and/or the sub Achimov formation and is overlain by Tangalovskaya Series. The Achimov formation occurs at 3500–4070 m (TVDSS) within the area under study.

According to the paleographical scheme of Northern Siberia in Early Valanginian time there was an epicontinental sea basin with maximum depths of 200–400 m (Kontorovich et al., 2014) within the area under study. Larger part of clastic material was transported from the Yenissey Ridge, Siberian platform, Altay-Sayan area and Central-Kazakh massif, and, to a less degree, from the Urals.

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Integrated analysis of geological and geophysics data, well logs, 3D seismic data and core was conducted for the purpose of detailed study of $Ach_{5-6}$ geological structure, prediction of reservoir rocks, optimization of exploration and field development patterns. Considering that reservoirs of Achimov formation have low-permeability, the hydrofracturing is used to stimulate oil production. Detailed study of the geological structure is a critical task nowadays, as a number of fields have high watercuts.

## Factual material and research methods

Sedimentological analysis of the Achimov formation was conducted on the cores from 12 wells. The total meterage of the studied core was 567 m with 82% core recovery. Facies were recognized on the basis of diagnostic signatures presented in papers of Russian (Alekseev, 2002; Baraboshkin, 2011; Zhemchugova, 2014, etc.) and foreign authors (Stow, 1976; Normark, 1970, 1990; Mutti, 1992; Lowe, 1982; Walker, 1992; Einsele, 1992; Reading, Richards, 1994, etc.). The results of lithological core research and reservoir properties made in Tyumen Petroleum Research Center were used to characterize lithotypes and facies. For well log correlations theauthors used lithofacies analysis (Alekseev, 2002) and sequence stratigraphy (Catuneanu, 2006). Facies maps of $Ach_{5-6}$ were built on the basis of comprehensive core analysis, well logging, seismic attribute maps (acoustic impedance, coherency, seismic facies, amplitudes), gross thickness and NTG maps. Areas with great potential for drilling were selected on the basis of pressure transient analysis, well logging, seismic materials, and facies models of productive deposits.

## Composition, structure and depositional settings

Reservoir rocks of Achimov formation are mainly presented by very fine-grained and fine-grained, rarely by medium fine-grained sandstones. According to mineralogical composition, sandstones and siltstones are arkoses that are the clastic products of disintegration of granitoids and metamorphic shale feldspar. It has been observed that quartz content predominates over feldspar. The content of rock fragments does not exceed 25% (Figure 1). The content of cement in sandstones and coarse-grained siltstones changes in wide range from 2.5 to 38%. The cement is clayey, carbonated, and regenerative. Chlorite predominates among clay minerals of cement. Calcite prevails among carbonate minerals. Regenerative quartz and feldspar cement which content does not exceed 0.5–1.0% can be encountered. By the X-ray diffraction analysis of the clay fraction an increased content of illite-smectite mixed-layer (up to 30–35%) was detected in the cement of Ach 6 sandstones and siltstones. The content of swelling clay minerals of illite-smectite mixed layer is 1–28% (Figure 1). The rocks are water-wet.

The negative influence of the following secondary processes was established on the reservoir properties of rocks: carbonation, chloritization, pelitization and hydration of biotite, regeneration of quartz and feldspars (only at high intensity). The process of solving feldspars and rock fragments, and kaolinitization exert some positive influence.

Rocks are characterized by very low permeability (mostly <1mD). In some individual wells only the permeability increases up to 30 mD as the content of medium-grained fraction grows in sandstones.

There are two conceptual models of the depositional genesis of the Achimov formation: delta front/avandelta deposits (Alekseev, 2014, etc.) and submarine fans (Nezhdanov et al., 2000; Gurari, 2003; Zverev, 2001; Borodkin et al., 2015; Syngaevsky, Khafizov, Shimansky, 2015, etc.). Structural features of rocks prove the sedimentological model of submarine fans.

According to the diagnostic signatures of facies (structure, texture, fauna, mineral inclusions, contacts and transitions, etc.), it was found that deposits were formed mainly by gravitational flows (grain, debris, and fluid) in the deep water part of the epicontinental sea basin. The rocks lack typical signs of shallow water (wave ripples; large-scale cross-bedding; signatures of subaerial exposure, storm and tidal processes). On the other hand, there are signs of sedimentary material input from the shallow water parts of the basin (carbonaceous

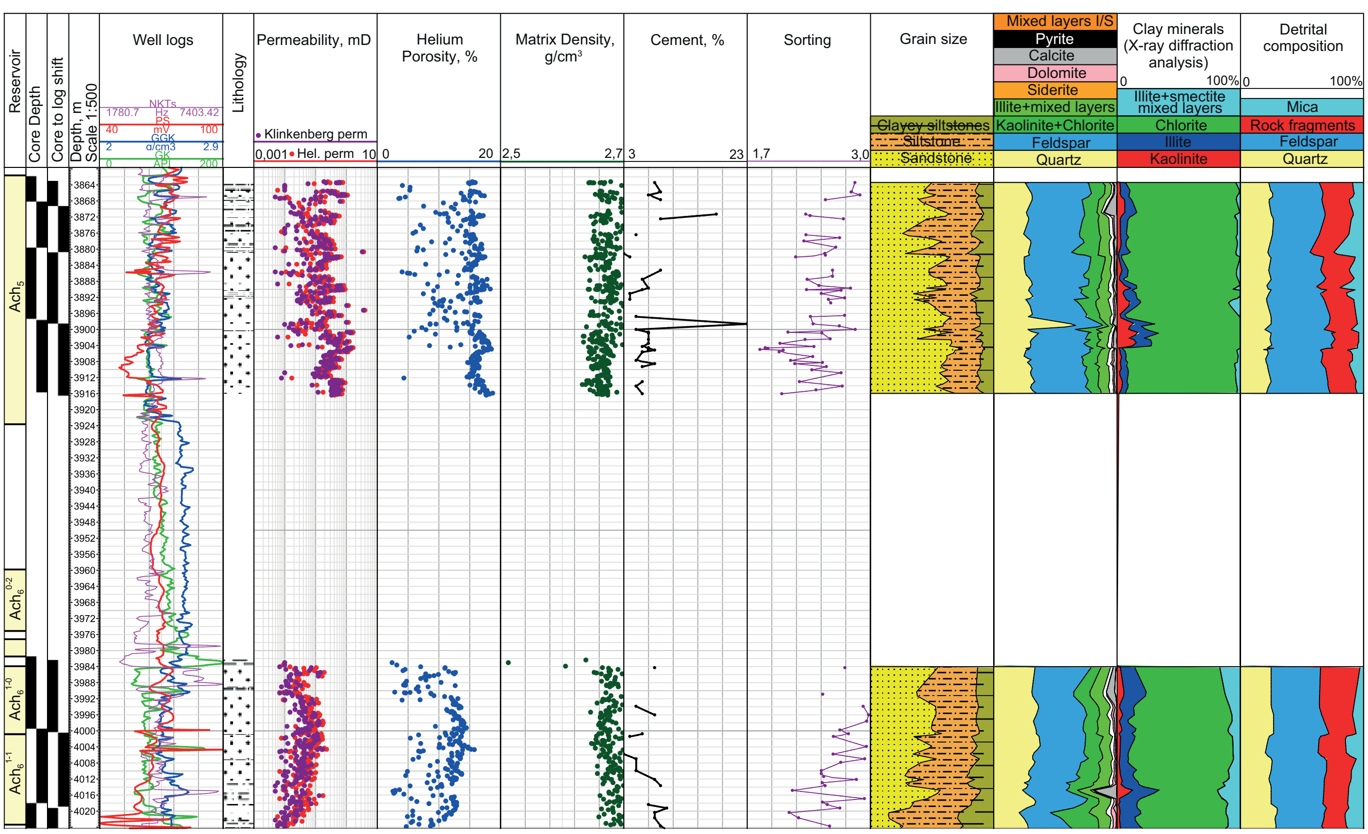


*Fig. 1. Lithology and petrophysics composite logs of Achimov formation of East-Urengoyskoe license. Lithology: 1 – sandstones, 2 – siltstones, 3 – clayey siltstones, claystones.*

detritus, shallow microorganisms and trace fossils). Bottom marks of loading, currents, and fame structures are abundantly developed at the bottom of sand layers (Figure 2a, 2c-d).

The Achimov formation can be characterized by the following: massive structure and graded bedding, texture of plastic deformations (intrusions, convolute, flaming, sand rolls), dish structures, water escape pipes, parallel-laminated, climbing current ripples, bioturbated structures are rare (Figure 2). Trace fossils: *Ophiomorpha, Asterosoma, Thalassinoides, Chondrites* can be found in single wells, in sediments of levees and inter-channel areas. The intensity of bioturbation can be significant.

*Graded bedding* is typical for deposits of turbidite flows. Numerous bibliography on turbidite flows and turbidites is presented in the papers of (Bouma, 2020; Mutti, 1992; Lowe, 1982; Stow, 1976; Prelat, 2009; Nichols, 2012, etc). The turbidite currents can be present in lakes (Dodd, McCarthy et al., 2018), deltas, seas and oceans, but to preserve structural features of turbidites, they should not be reworked by other currents. In fact, this determines the position of turbidites below storm wave base.The probable minimum depths are about 250–300 m (Walker, 1992), which does not contradict the regional data.

As a result of the sedimentological study of the Achimov formation cores, the following facies were identified: submarine feeding and distributary channels, submarine levees, channel edges and interchannel deposits, clay deposits of the slope and shelf, slump scars and depositional lobes. The conceptual structural model of the Achimov formation is presented in Figure 3a.

***The slope channels*** are not studies by core: they are recognized by the seismic data (Figures 3b, 3d). The transition from channels with levees to frontal crevasse splay is well identified on maps and sections in the acoustic impedance cube (Figures 3b, 3c). The main sedimentological sections of facies of the Achimov formation are presented in Figure 4.

***The distributary channels*** are represented by sandstones with massive texture, water escape pipes and dish structures are often found, that indicates an intensive loss of the fluid component during sedimentation period. Massive sandstones graded into typical turbidites from bottom-up. The lower contact of sandy interlayers is usually erosive (Figure 4a), emphasized by mudstones and clayey siltstone intraclasts. The presence of debris indicates the erosion caused by high-density turbidite flows.

*Admixtures:* pyrite compounds, carbonaceous detritus.

*Interpretation:* The formation of submarine channel deposits was a result of high-density and low-density turbidite flows. Both large channels with levees and small channels can be encountered. Quite often the channels are built on each other, as a result the upper fine-grained sequences are eroded by subsequent flows.

Big slope channels are the main sediment transporters from the zone of shallow water shelf to the deep part of the basin. They are well identified on seismic (Figure 3b). Distributary channels can be meandering, braided,

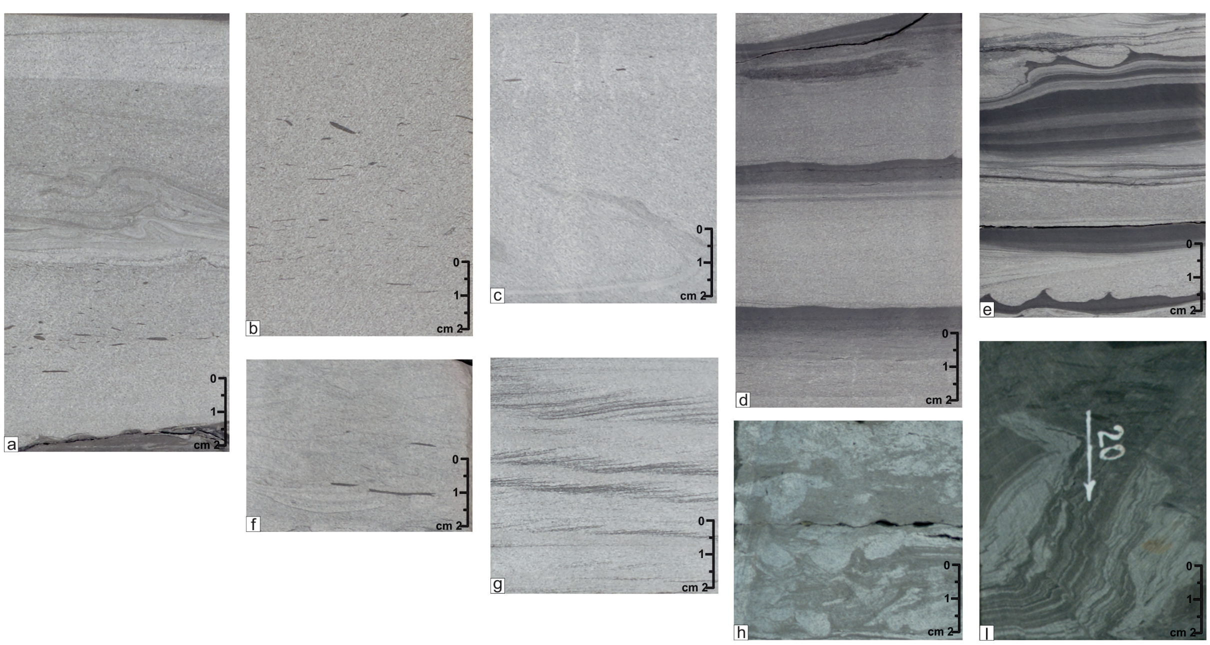


*Fig. 2. Srtuctural features of Achimov formation of East-Urengoyskoe field. a – sandstones with ripped-up clay clasts, convolute lamination and climbing ripples; b – sandstones with debris structure, with small intraclasts of clayey siltstones; c – sandstones with water escape pipes and flames; d – sandstones with gradational bedding; e – interlayering of sandstones and clayey siltstone. There are casts layers on the contact of load; f – dish structures in sandstones, with small clayey siltstone clasts; q – climbing ripples sandstones; h – bioturbation (Thalassinoides);i – fine to coarse siltstones with convolute lamination.*

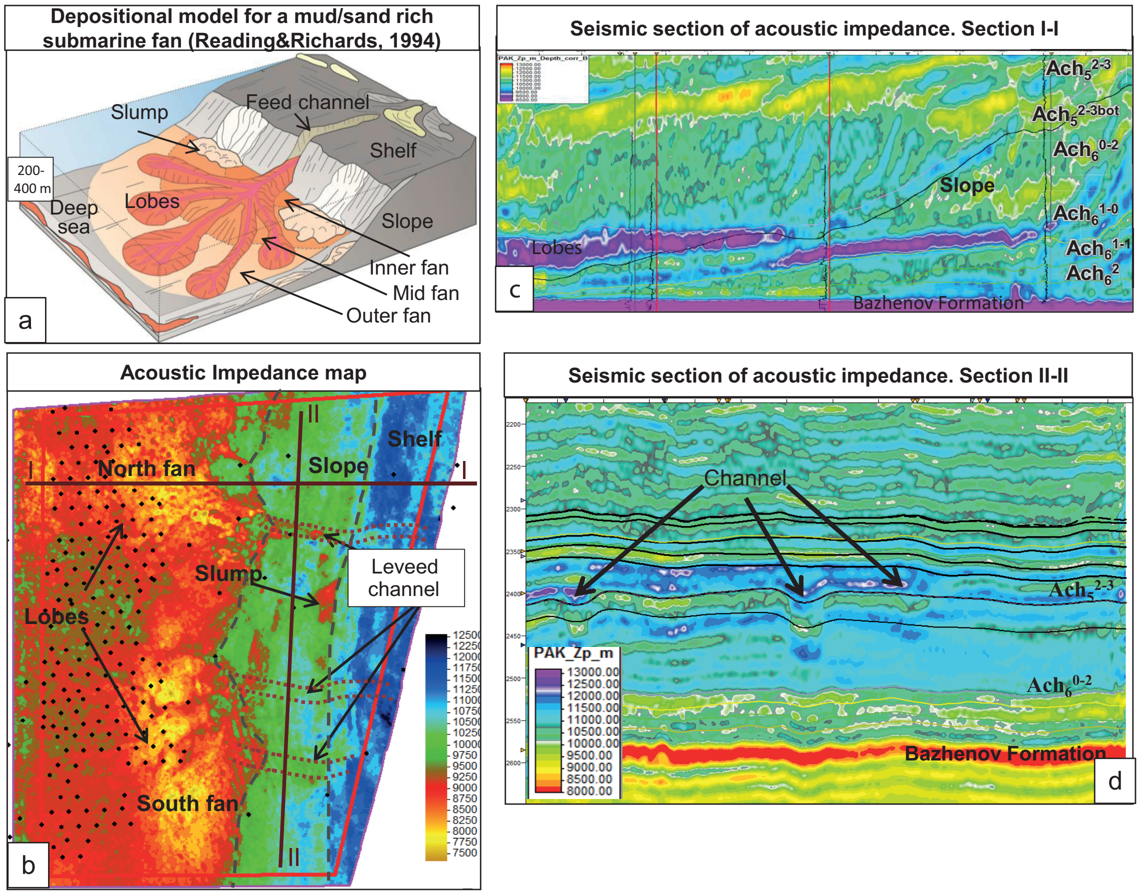


*Fig. 3. Conceptual model of Achimov formation (a) and morphological elements of submarine fan picked by seismic survey results (b-d)*

and straight types. The sand body in section view is U-shaped (Figure 4).

*Thickness*: up to 30 m.

*Well log signature:* blockyshaped, low gamma-ray (5–10$^0$API).

**The turbidite lobe facies** is represented by very fine- to fine-grained sandstones, coarse-grained siltstone with thin interlayers of mudstone and clayey siltstone. The structure in sandstones and siltstones is massive, debris, gradational, with plastic deformations, fluidal, horizontal, partly with climbing ripples (Figure 2g). There are load structures on the contacts of bedding. Turbidite lobes are characterized by layers of sandstones with massive and graded structures without features of channel impact (Figure 4b).

*Admixtures andother features*: carbonaceous detritus, clayey siltstone clasts of elongated and flattened shape.

*Interpretation*: when leaving the channel, the turbidite flows spread to form submarine levees well defined in the landscape. Lobes consist of compensation cycles, each of them represented by turbidites filling the low, located between sediments of older turbidite flows projected out in the landscape. The structure of compensation cycles can feature sandstone tubridite layers thickening and thinning up. Depositional lobes develop during slope gradient change. As the flow meets rapid slope gradient at such knickpoint (transition point) the channels are replaced by frontal splays (Figure 3b, c). The sand body in side view has a shape of flat, elongated lenses (Figure 4).

*Thickness*: up to 15–20 m.

*Well log signature*: medium gamma-ray (7–12$^0$API).

**The submarine levee facies/interdistributary areas** are represented by interlayering of sandstones, siltstones, and mudstones (Fig. 4c). The thickness of sandstones changes from 2 to 50 cm. Clayey siltstones and mudstones are 1–10 cm thick. Moving away from the channel, sand interbeds become thinner.

*Structure:* thin bedding, gradational, with plastic deformations, debris, climbing current ripples, convolute, occasional bioturbation (Figure 2h).

*Trace fossils:* Thalassinoides, Fugichnia, Ophiomorpha and Phycosiphon are in places.

*Admixtures and other features*: plant detritus, small lenses of coal, shell detritus.

*Interpretation:* V-shaped levees are formed on the channel edges and gradually pinch out inward the basin. The height of levees usually decreases down the submarine fan. The channels become less deep. The presence of suspended fines results in growth of the levees. The levees consist of different proportions of laminated sandstones and fine-grained turbidites.

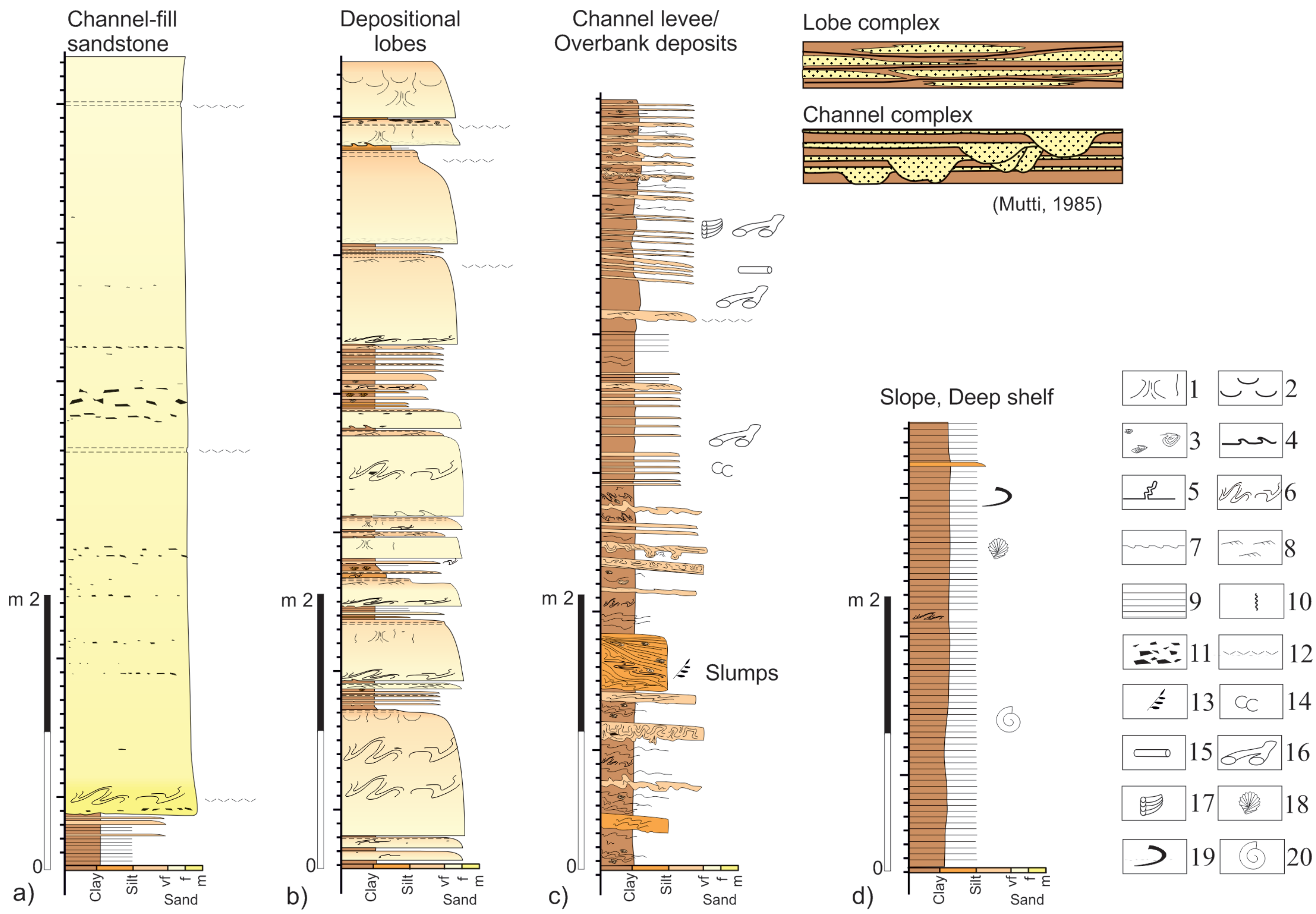


*Fig. 4. Typical sedimentological logs of Achimov formation. Structures: 1 – water escape structures; 2 – dish structures; 3 – sand rolls; 4 – flaming; 5 – injection structure; 6 – convolute; 7 – loadintrusion; 8 – climbing ripple; 9 – horizontal; 10 – bioturbation. Inclusions: 11 – clayey clasts; 12 – thin layers of carbonaceous detritus; 13 – scatteredcarbonaceous detritus; ichnofacies: 14 – Palaeophycus; 15 – Planolites; 16 – Thalassinoides; 17 – Teichichnus. Fauna: 18 – fish scales; 19 – onychitis; 20 – ammonites. On the grain-scale ruler: Svf –very fine sandstone;Sf – fine-grained sandstone; Sm – medium-grainedsandstone*

*Thickness:* 0.10–3.8 m.

*Well log signature:* increased gamma-ray (7–14$^0$API).

**Slump facies** is represented by interlayering of fine-grained clayey siltstones, coarse-grained siltstones, very-fine grained sandstones and silty mudstones. The primary bedding was destroyed by sediment slump.

*Trace fossils:* not common.

*Admixtures and other features:* carbonaceous detritus, shell detritus, small clasts of clayey siltstone.

*Interpretation:* Poorly consolidated sediments slump on the flat slope under the action of gravity.

*Thickness:* 0.45–6.5 m.

*Well log signature:* average and increased gamma-ray (10–12$^0$API) and spontaneous potential (SP).

***Slope*** and **deep shelf facies** are represented by clayey siltstones and silty mudstone (Figure 4d).

*Structure*: microbedding, plastic deformation.

*Fauna:* ammonites, foraminifera, bivalves, onychitis, fish remains.

*Admixtures and other features:* carbonaceous detritus, shell detritus, organic matter, carbonate nodules, pyrite.

*Interpretation:* suspension precipitation, low sedimentation velocity, slumping under gravity.

*Thickness:* up to 10 m.

*Well log signature:* increased gamma-ray (9–14$^0$API).

Facies models of $Ach_{5\text{-}6}$ reservoirs are represented in the Figure 5.

The $Ach_5^{2\text{-}3}$ is characterized be the thickest and most productive sandstones. Two parasequences ($Ach_5^2$ and $Ach_5^3$) are identified in $Ach_5^{2\text{-}3}$ based on integrated analysis of core, well log data and seismic. The thickness of these parating shale break changes from 2 to 26 m. For every parasequence submarine fans were identified: northern and southern fans with lobe systems. Northern fans have increased sandstone thickness, compared to southern and can represent exploration targets for drilling new wells. Submarine fans of $Ach_5^2$, $Ach_5^3$ are of mixed sand-clayey type. Lobes and distributary channels are mainly made of sandstones and coarse-grained siltstones. Their content in the section is >70%.

$Ach_6$ deposits formed on the flat slope by clayey systems. Lobes are elongated. Sand sediments are concentrated next to the channels (Figures 5c, d).

Based on a comprehensive analysis of the core,

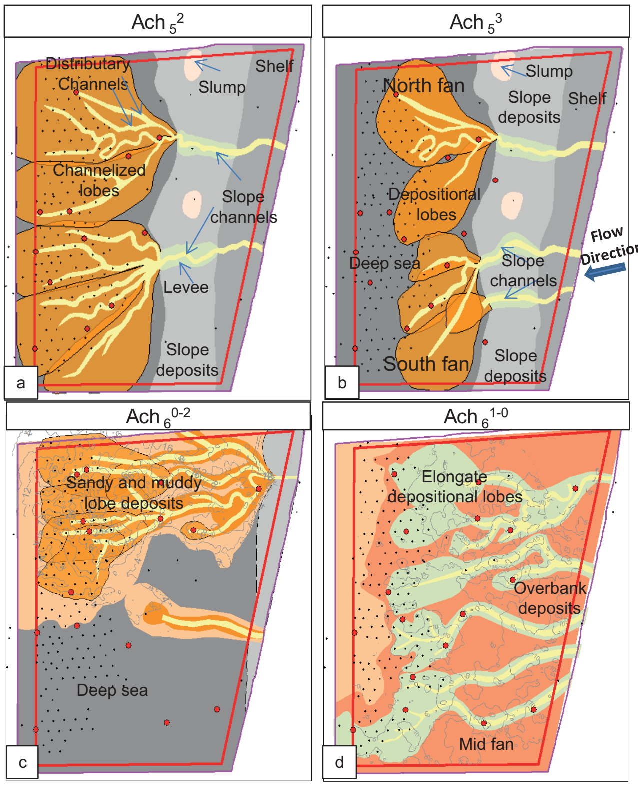


*Fig. 5. Facies models of reservoirs: a – $Ach_5^2$; b – $Ach_5^3$; c – $Ach_6^{0-2}$; d – $Ach_6^{1-0}$. Red spots – wells with the core*

logging, seismic, and well testing data from theAchimov formation, no connectivity of individual lobes was found, which is the reason for varying fluid inflows in the wells. To update the saturation model of the southern submarine fans of $Ach_5^2$ and $Ach_5^3$ reservoirs poorly covered by drilling, interval-by-interval testing as well as wireline formation tests are recommended.

## Summary

The sedimentological analysis of the Achimov formation core showed that the sediments were formed by gravity flows, below the storm wave base, in a relatively deep-water part of the shelf. The material was supplied from east to west. Net-reservoir rocks with the maximum sandstone thicknesses and best reservoir properties (reservoir classes IV and V) are confined to the underwater channels and the proximal parts of turbidite fans of the $Ach_5$ group of reservoirs.

The sediments of the $Ach_6$ group of reservoirs differ from the overlying $Ach_5$ sediments by higher content of mica, carbonate minerals (calcite) and admixture of illite-smectite mixed-layer minerals in the sandstones and siltstones cement and very low permeabilities ($<1*10^{-3}$ μm$^2$).

On the basis of a comprehensive analysis of the core, well logging, and seismic materials, the geological structure of the Achimov stratum was detailed and facies maps of $Ach_5^2$, $Ach_5^3$, $Ach_6^{0-2}$, $Ach_6^{1-0}$ reservoirs were built. Underwater sand lobes and distribution channels are prime targets for exploration and development of the Achimov formation.

Depending on the structure and saturation model of submarine fans, decisions should be made on adjusting the trajectory of horizontal wellbores and optimizing the hydraulic fracturing design.

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