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Historical and Geological Modeling of the Processes of Hydrocarbon Generation in the Hettangian–Aalenian Deposits of the Ust'-Tym Megadepression[1]

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Abstract—Analysis of the geologic structure of the Hettangian–Aalenian deposits of the Ust'-Tym megadepression was carried out. The history of the formation of traps in the Hettangian–Aalenian complex has been reconstructed on the basis of a comprehensive interpretation of seismic materials and deep-drilling data. The oil and gas potential has been estimated. The time of the subsidence of the Togur Formation into the oil window has been determined, and the history of the generation of liquid hydrocarbons (HC) by the organic matter (OM) of the Togur Formation has been reconstructed.

The Lower Jurassic and Aalenian deposits overlap the rocks of the pre-Jurassic basement with disagreement and are distributed almost over the entire study area. The complete section of the Hettangian–Aalenian deposits is in the most submerged parts of the territory. The section includes the Urman, Togur, and Salat/Peshkov Formations and the lower Tyumen Subformation. Three oil and gas subcomplexes—Hettangian–Early Toarcian ($U_{16–17}$), Toarcian–Aalenian (U_{15}), and Aalenian ($U_{11–14}$) — are distinguished within the Hettangian–Aalenian sediments.

Closed positive structures that can serve as hydrocarbon traps have been identified in each of the subcomplexes. Positive structures developed in the Jurassic, Berriasian–Early Aptian, and Aptian–Albian–Turonian time were inherited and finally formed at the post-Turonian stage only. The authors carried out a quantitative assessment of the total oil resources of the D_0 category for all promising objects, taking into account the success rate.

The heterogeneous organic matter of the Togur Formation is the main source of hydrocarbons in the Hettangian–Aalenian complex. The Togur Formation began to enter the oil window (OW) about 115–110 Ma and fully entered it about 5 Ma. The escape of rocks from the zone of the oil window began about 48 Ma and still continues.

The history of the generation of liquid hydrocarbons by the organic matter of the Togur Formation has been reconstructed for types II and III of kerogen. For type II, the generation began about 94 Ma, at the beginning of the Late Cretaceous (Cenomanian), and for type III, it began in Turonian time (89.8 Ma). The most significant volumes of liquid HC were generated in the last 5 Myr.

Potential hydrocarbon traps existed throughout the generation process, which allowed accumulation of the generated hydrocarbons in the Hettangian–Aalenian complex. Comparison of the estimated oil resources of the D_0 category in the traps of the Hettangian–Aalenian complex with the volumes of generated hydrocarbons leads to the conclusion that the traps might have been filled. The results obtained in the course of the study suggest that the Hettangian–Aalenian complex is oil- and gas-promising and the Togur Formation is the main source of hydrocarbons.

Keywords: Ust'-Tym megadepression, Hettangian–Aalenian deposits, Togur Formation, geological structure, petroleum potential, hydrocarbon generation

INTRODUCTION

Upper Jurassic deposits (horizon U_1) in the southeast of West Siberia are the most promising in terms of petroleum potential, most of the oil and gas fields are associated with this horizon. Seventeen hydrocarbon (HC) fields are known in the study area, in the Ust'-Tym megadepression and adjacent slopes of first order positive structures. Thirteen fields are confined in the Upper Jurassic horizon U_1, two fields in the Cretaceous sediments (B_{13}, B_6), one each for the Middle Jurassic (U_6) and Paleozoic (M) oil and gas horizons. Currently, hydrocarbon deposits have not been identified in the Lower Jurassic and Aalenian, oil inflows have been obtained from wells in Tolparov and Vartov areas.

The fund of Upper Jurassic traps is almost exhausted in the Tomsk region. The discovery of new deposits of oil and gas in the poorly studied and deep-lying sedimentary horizons is important for the reproduction of the resource base of the region. The Lower–Middle Jurassic complexes in the Ust'-Tym megadepression are of great interest to geologists, a number of publications are devoted to the study of the geological structure and the assessment of the prospects for pe-

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troleum potential (Kontorovich et al., 1964; Egorova, 1992; Moskvin et al., 1999; Gurari et al., 2005; Lobova et al., 2014; and others).

An integrated approach using all geological and geophysical materials makes it possible to detail the geological structure of the Hettangian–Aalenian deposits, which corresponds to the current degree of study, and to allocate promising objects. The presence of seal rock, reservoir and source of oil generation (Togur Formation) allows us to consider the Hettangian–Aalenian complex as an oil prospective.

The first oil in West Siberia was obtained in 1954 on the southern side of the Ust'-Tym depression in the Kolpashevskaya support well No. 2. V. Uspensky and F. Gurari initially estimated the age of the paraffin Kolpashevo oil as Paleozoic. A. Kontorovich, O. Stasov, A. Fomichev for the first time pointed to the Mesozoic nature of Kolpashevo oil (1964). For the first time, the same researchers noted that the Togur Formation (in those years, a unit) is an oil source in favorable lacustrine facies.

The study area is located in the Tomsk region and belongs to the Vasyugan and Paidugina petroleum regions (PR). In tectonic terms, the object of study is confined to negative structure of the first order—the Ust'-Tym megadepression, which borders on positive structures—the Kurzhin ridge in the east, Ob'-Vasyugan ridge in the west and the Parabel' inclined megarange in the south.

The object of the study is the Hettangian–Aalenian deposits of the Ust'-Tym megadepression and the adjacent territory. The purpose of this work is to determine the conditions and time of the formation of potential hydrocarbon traps and modeling the processes of oil formation in the Ust'-Tym sedimentary basin.

The research material includes data on the seismic time profiles with a length of 2214 km, deep drilling of 103 wells, digital models of the distribution of vitrinite reflectivity in the roof and base of the Jurassic, pyrolysis data on 7 wells and the values of the modern C_{org} of the Togur Formation.

RESEARCH METHODS

With the restoration of the conditions and time of formation of positive structures—potential hydrocarbon traps using the "power method", the history of the tectonic development of the study area was reconstructed. The method is based on the assumption that the zones of the greatest thicknesses of seismic-geological complexes were deflection areas, areas with reduced thicknesses—areas of relative upliftment (Mashkovich, 1976; Kontorovich, 2002).

For paleoreconstructions, regionally developed transgressive clay units were taken for leveling surfaces in West Siberia. Reference seismic horizons are confined to clay units: II^a (base of the Bazhenov Formation, Tithonian stage), III (Koshai unit of the Alym Formation, Aptian stage), IV (Kuznetsov Formation, Turonian stage).

The approaches used to perform basin modeling are based on modeling the transformation kinetics of the insoluble part of the dispersed organic matter. The theoretical foundations of modeling oil and gas formation processes were developed starting from the second quarter of the 20th century in the USSR (Russia), North America, West Europe and other regions, the basis for which was the sedimentary migration theory of naftidogenesis. Within the framework of the theory, a consistent system of physicochemical models was formed, the models described the stages and processes of naftidogenesis (Vassoevich, 1967; Kontorovich et al., 1967; Kontorovich, 1970).

The source of hydrocarbons in sedimentary rocks is organic matter fossilized in sediments and rocks, the composition of which depends on its biological nature and the nature of transformations in sedimentogenesis and diagenesis. In the course of diagenesis, biogeochemical processes take place in sediments, as a result of which lipid components accumulate in aquageneous organic matter and protopolymerlipid kerogens and partly melanoidins are formed. This substance is called aquageneous. Organic matter coming from land is terragenous; protokerogen in its composition is represented by lignin and melanoidins and contains relatively few polymer lipids.

Further conversion of OM to the appearance of liquid and gaseous hydrocarbons occurs during catagenesis. Protocatagenic phase of gas formation is released, during which hydrocarbon gases, mainly methane, are formed, the main phase (zone) of oil formation (oil window) (Kontorovich et al., 1967; Vassoevich, 1967) and the late catagenous phase of the formation of fat condensate gas and further dry hydrocarbon gas is the main phase of gas generation (gas window) according to S. Neruchev.

For the first time, the reconstruction of the history of oil formation in sedimentary basins was carried out in the USSR in the 60–70s of last century such scientists as N. Vassoevich, A. Kontorovich, A. Trofimuk, S. Neruchev and others. The theory built by these scientists, and then the methodology, was called the "historical and geological reconstruction of oil and gas production processes", and later in the western literature—"basin modeling".

Calculative experiments on the reconstruction of the processes of subsidence of the sedimentary strata and the processes of naftidogenesis in the present work were carried out in the software package "TemisFlow", developed by the company "Beicip-Franlab".

GEOLOGICAL STRUCTURE, HISTORY OF FORMATION OF POTENTIAL HYDROCARBON TRAPS AND ESTIMATION OF THE PETROLEUM POTENTIAL OF THE HETTANGIAN–AALENIAN OIL AND GAS COMPLEX

The Lower Jurassic and Aalenian deposits unconformably overlap the rocks of the pre-Jurassic basement and are distributed practically over the entire study area, with the exception of the most elevated areas represented by structures of the pre-Jurassic basement. The thickness of the complex reaches 440 m.

Hettangian–Aalenian deposits are limited in the roof by the Y_{10} coal bed, which has a regional distribution, on which the reflecting seismic horizon I^a is formed. (Kontorovich et al., 2017). In the structural plan of this surface, the Ust'-Tym megadepression is distinguished (area is 16,200 km^2, –2800 isohypse outline, 300 m amplitude) and large positive 0 and I orders adjacent to it (Fig. 1).

Three petroleum-bearing sub-complexes are distinguished in the structure of the Hettangian–Aalenian deposits: Hettangian–Early Toarcian ($U_{16–17}$), Toarcian–Aalenian (U_{15}) and Aalenian ($U_{11–14}$) (Fig. 2).

The Hettangian–Lower Toarcian subcomplex is distributed only in the depressed zones of the study area and is represented by the Urman and Togur Formations, dating from the Hettangian–Plinsbachian and Early Toarcian, respectively. The Urman Formation lies at the base of the subcomplex; it consists of 3 subformations, composed mainly of sandstones, gravelites, siltstones and mudstones, with

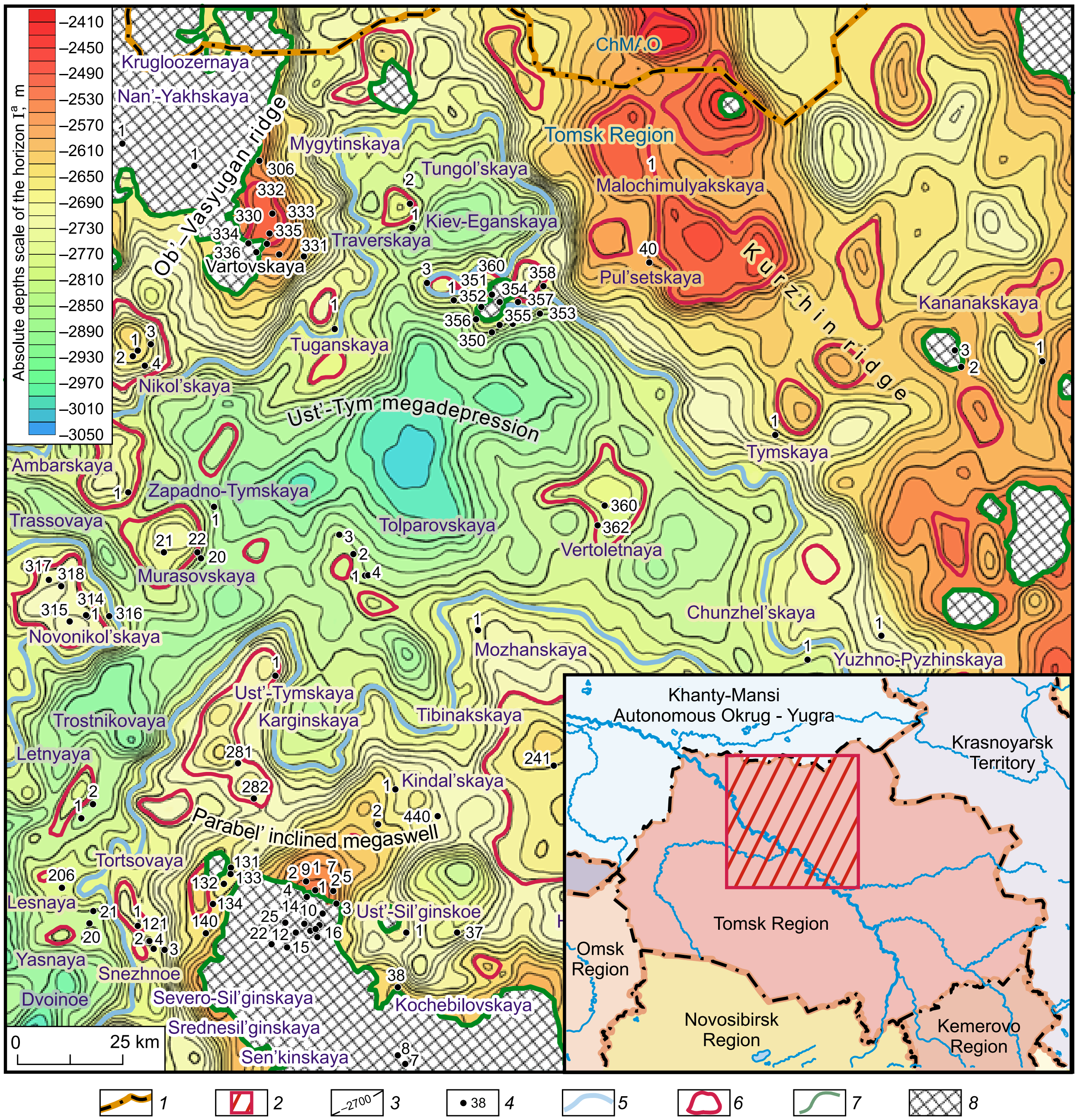

Fig. 1. Structural map of the roof of the Hettangian–Aalenian complex. *1*, administrative boundaries; *2*, study area; *3*, isohypses of the horizon I^a; *4*, wells; *5*, border of Ust'-Tym megadepression; *6*, closed positive structures; *7*, Hettangian–Aalenian deposit boundaries; *8*, pre-Jurassic basement.

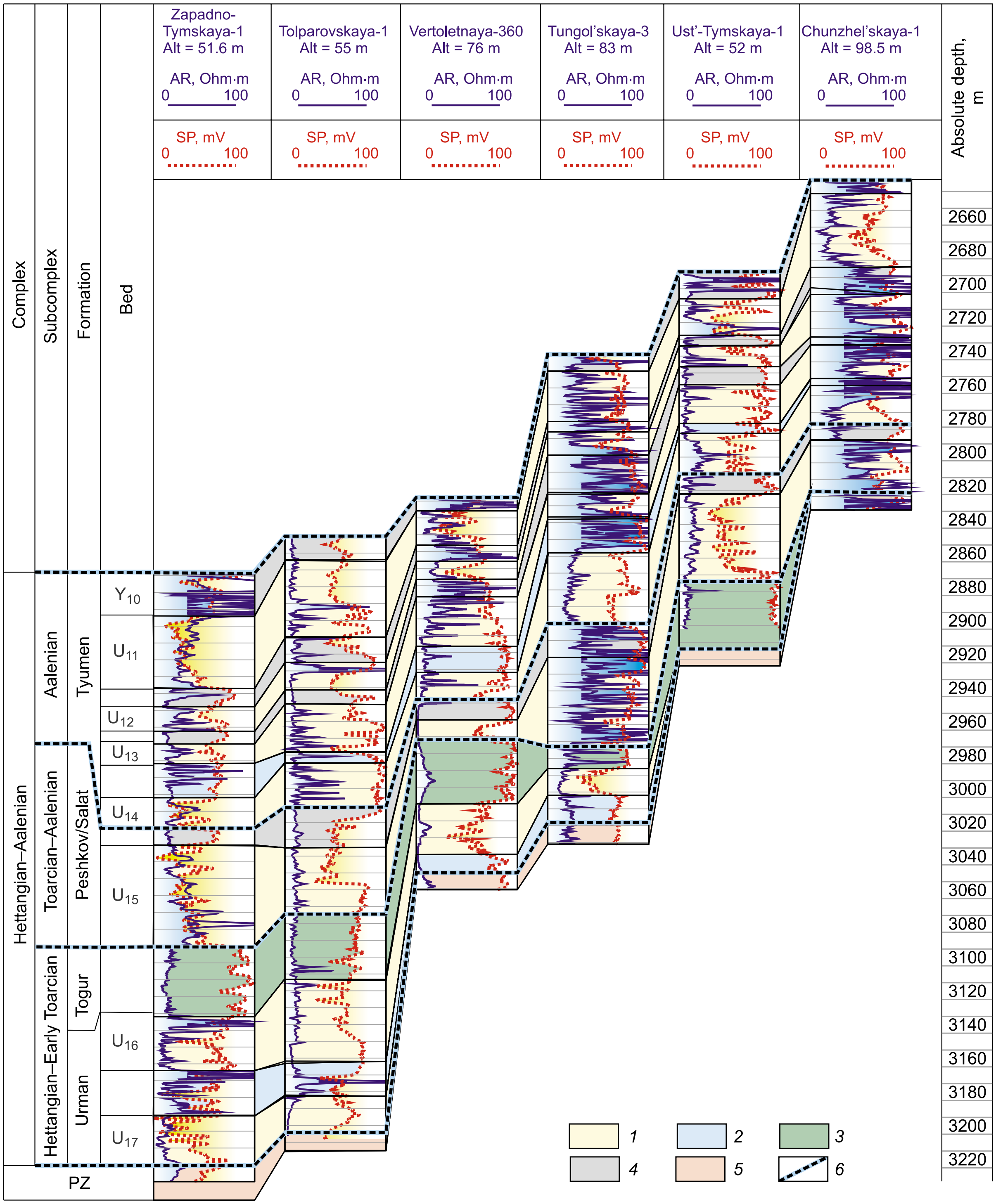

Fig. 2. Correlation scheme for the wells of the Ust'-Tym megadepression on the roof of the Y_{10} coal bed. *1*, sandstone horizons; *2*, clay-carbon units; *3*, Togur Formation; *4*, coal beds; *5*, pre-Jurassic deposits; *6*, subcomplex boundaries.

rare interlayers of coal and charred remains (Gurari, 2004). The thickness of the formation varies from 8 to 92 m. The $U_{16–17}$ sandstone formations of oil and gas bearing interest are distinguished in the subcomplex.

The Togur Formation limits the subcomplex in the roof. It is represented by black thin layer mudstones, enriched with organic matter (OM), there are interlayers of siltstone and fine-grained sandstones. Thickness varies from 10 to 40 m. F. Gurari first identified a retinue in 1960 in the section of the Kolpashevskaya-2 well and identified it as the Togur unit. Later, as noted above, A. Kontorovich, O. Stasova and A. Fomichev found that Togur's mudstones have a sufficiently high generation potential and serve as a potential source of hydrocarbons for deposits in the basal horizons of the sedimentary cover (Kontorovich et al., 1964). Studies in this direction were continued by Kontorovich et al. (1967, 1995), Kostyreva et al. (2014). In 1976, the Togur unit was transferred to the rank of formation (Decision..., 1978).

Toarcian–Aalenian subcomplex. It is represented by the Peshkov Formation, dated by the second half of the Early Toarcian–Early Aalenian. The formation is composed of sandstones and siltstones, there are clay and carbonaceous interlayers, the thickness varies from 0 to 44 m, the sandstone horizon U_{15} is considered as a reservoir. In the roof of the subcomplex a carbonaceous-clay unit Y_{14} is released, which serves as a seal.

The Aalenian subcomplex is represented by the Lower Tyumen subformation of Tyumen Formation, dated to the Upper Aalenian. The subformation is composed of sandstones and siltstones, contains coal beds, its thickness reaches 182 m. The reservoir is a group of hydrodynamically coupled $U_{11–14}$ sandstone units, which alternate in section with carbonaceous-clay units $Y_{11–13}$. The subcomplex is bounded at the top by a Y_{10} coal bed that plays the role of a fluid seal.

Early Triassic rift genesis preceded the formation of a sedimentary cover; as a result of rifting, the Ust'-Tym megadepression was formed. The Ust'-Tym depression subsided relative to adjacent positive structures and was filled with sediment from them during the Hettangian–Aalenian time. The main positive structures were formed above the erosion-tectonic structures of the basement.

The Berriasian–Early Aptian period was characterized by intensive processes of relative uplift in the north of the territory, growth of local structures in the east and south, and relative deflection of the central part. The structures of the Ob'–Vasyugan and Kurzhin ridges experienced an upward trend in the Aptian–Early Turonian, while the area of relative deflection shifted to the southeast. In the post-Turonian–Cenozoic stage of development, intensive growth was experienced by the structures of the Parabel' inclined megarange, the deflection area shifted to the north and west of the territory.

Structural and lithological traps and local uplifts control the hydrocarbon accumulations of the Hettangian–Aalenian complex. An analysis of the history of tectonic development showed that by the end of the Aalenian in the reliefs of the roof of the pre-Jurassic basement and the Togur Formation most of the local structures (32) had already been formed; by the beginning of the Aptian, their number increased to 37, and by the Turonian age to 42 (Fig. 3). Thus, over time, the relief of the Hettangian–Aalenian horizon became more dissected, and the size of the depression area increased. Forty-five closed elevations of the III–IV orders are currently distinguished in the structural plan of the roof of the Hettangian–Aalenian complex.

The analysis showed that the main stages of the tectonic development of large structures of the first order, such as the Ust'-Tym megadepression, Ob'–Vasyugan and Kurzhin ridges and the Parabel' inclined megarange were Early Jurassic and Cenozoic. The formation of local uplifts took place throughout the Mesozoic–Cenozoic time, but these processes were most intensive in the Jurassic and Early Cretaceous.

ESTIMATION OF THE OIL AND GAS POTENTIAL OF THE LOWER–MIDDLE JURASSIC DEPOSITS

Perspective objects were identified in the Hettangian–Early Toarcian, Toarcian–Aalenian and Aalenian subcomplexes to determine the prospects of oil and gas potential using structural surfaces along the top of the formations and maps of their effective thicknesses. According to the analysis of well testing, hydrocarbon deposits and aquifers were identified; untested objects were classified as promising. Hettangian–Aalenian sandstone horizons are not widespread throughout the study area and are often replaced by impermeable seals, which creates favorable conditions for the formation of structural and lithological traps. The estimation of the D_0 category resources was carried out by the method of comparative geological analysis for the quantitative assessment of the oil and gas potential (Buyalov and Nalivkin, 1979). The average values of the calculated parameters of the facilities of the Vasyugan (Gerasimov, Solonov, Urman and Shirot fields) and Kaimysovy (Festival Field) OGA were taken as the standard.

The total geological resources of the D_0 category of the Hettangian–Aalenian oil and gas complex are 1,008,600 thousand tons, the total recoverable resources are 229,600 thousand tons. An additional parameter, the "success rate" (SR) is introduced for correctness in the assessment of resources and is equal to the quotient of open deposits or deposits to the total number of drilled prospective objects. Each territory is characterized by its attitude; the average value in the southeast of West Siberia is about 0.3; for less studied territories and intervals, this indicator is lower—for sandstone horizons $U_{11–15}$—0.1; for sandstone horizons $U_{16–17}$ SR has a higher value (0.25).

The total geological resources of the D_0 category of the Hettangian–Aalenian complex, taking into account the success rate, amounted to 104,960 thousand tons, the total recoverable resources amounted to 23,780 thousand tons.

MODELING OF GENERATION PROCESSES

The method of comparative geological analysis was used to assess potential hydrocarbon resources; however, even with a close geological structure of the object and standard being assessed, it is difficult to estimate hydrocarbon volumes without considering the degree of OM. For a more accurate assessment of the prospects, the scale of generation and the time of entrance of the source rock (Togur Formation) in the main zone of oil generation (oil window) were determined.

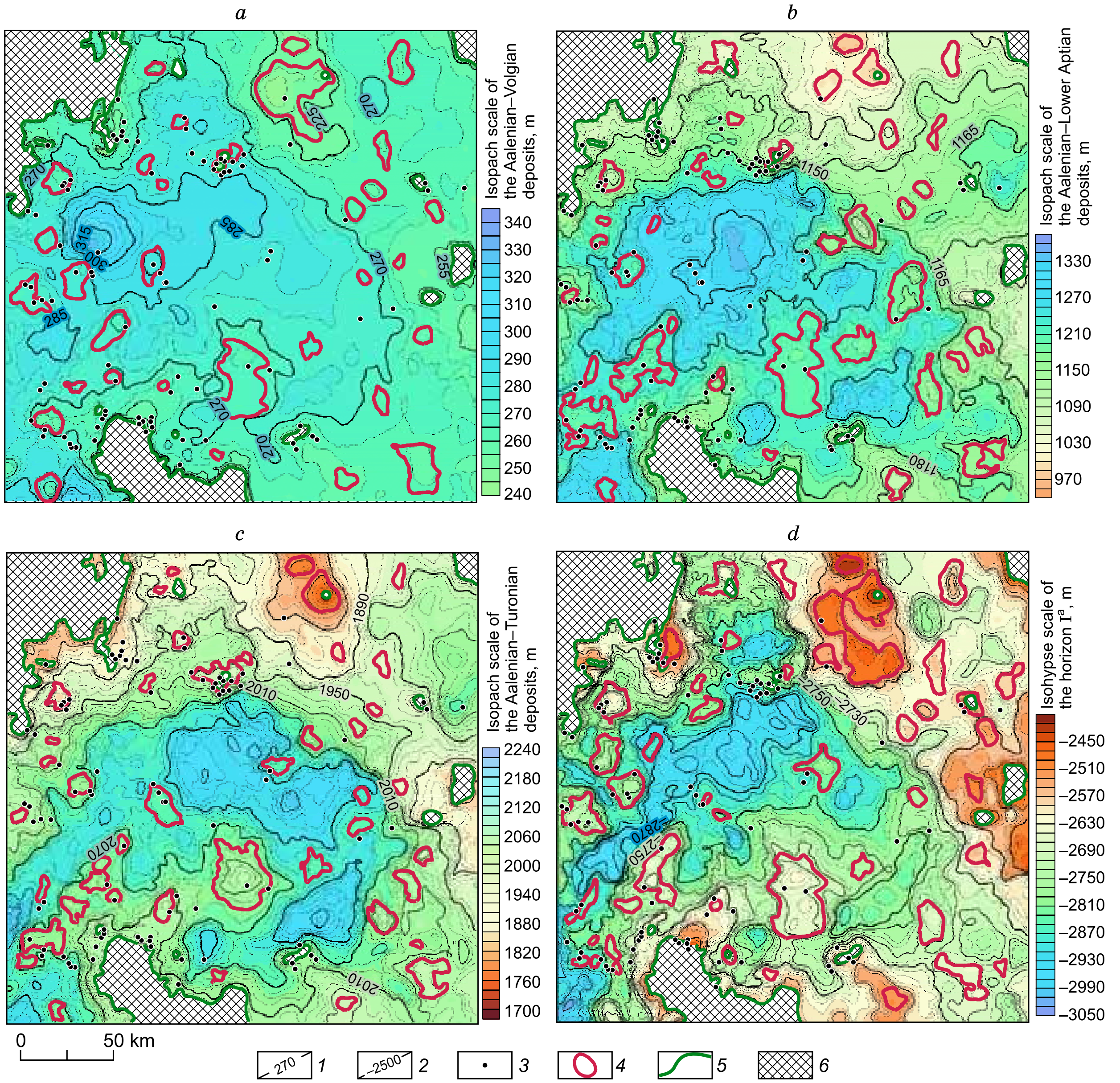

Fig. 3. Dynamics of changes in the structure of the Hettangian–Aalenian complex during the formation of the Bazhenov Formation (horizon IIª) (Tithonian) (*a*), Alym Formation (III) (Aptian) (*b*), Kuznetsov Formation (IV) (Turonian) (*c*); modern structure (*d*). *1*, isopachs; *2*, isohypses; *3*, wells in which the Hettangian–Aalenian deposits are discovered; *4*, closed positive structures; *5*, distribution zone of the Hettangian–Aalenian deposits; *6*, pre-Jurassic basement.

Structural-lithological and thermal models of the Mesozoic–Cenozoic sedimentary cover and models of hydrocarbon generation for different types of kerogen were built to reconstruct the history of hydrocarbon generation by organic matter of the Togur Formation.

The structural-lithological model makes it possible to recover the history of sedimentation, takes into account the thickness of the selected complexes and the depth of their stratification, lithological and physical characteristics.

The structural and lithological models were based on maps of lithotypes and structural maps on the roof of the pre-Jurassic basement, the Urman, Togur, Peshkov, and Salat Formations, the Lower Tyumen subformation, the Tyumen, Naunak (Vasyugan), Bazhenov, Tar, Alym, Pokur, Kuznetsov, Ipatov and Talit Formations. The absolute age of the stratigraphic units was taken in accordance with ICS 2008. Distribution maps of lithological types were constructed by area and in the section. The generation properties of lithotypes were selected from standard libraries.

The main source of hydrocarbons in the Hettangian–Aalenian complex is heterogeneous in composition of the OM of the Togur Formation (Kontorovich et al., 1964; Kostyreva et al., 2014), genetically associated with higher terrestrial vegetation and lacustrine sapropel formed in large lakes, sometimes connected with the sea (Kontorovich et al., 2013). According to pyrolysis data in a number of wells in the central parts of the Ust'-Tym megadepression, rocks contain aquagenic OM biomarkers, as evidenced by low values of $\delta^{13}C$ (from –29 to –34‰) and the composition of hydrocarbons. In a number of other wells, the rocks contain mixed organic matter, which has a genetic connection with higher terrestrial vegetation, as evidenced by high odd to even *n*-alkanes concentration ratios (1.00–1.25) (Moskvin et al., 1999; Kostyreva et al., 2014). The Togur Formation is characterized by an average residual generation potential (HI) of about 300 mg HC/g of C_{org} (Fig. 4). Modern concentrations of organic carbon vary from 1.2 to 3.8%, the content of bitumoids varies from 0.22 to 0.63%.

The determination of the chemical-kinetic parameters of kerogen was not carried out within the framework of the work; standardized types described in the literature were used (Behar et al., 1997; Vandenbroucke, 2003; Bogorodskaya et al., 2005). The aquagenic OM corresponds to type II kerogen, mixed OM—III type, which is characterized by a lower hydrocarbon potential—about 235 mg HC/g C_{org}, which is characterized by a longer OM maturation process and smaller volumes of oil generation (Kontorovich and Melenevskii, 1988). The ratio of the mixed and aquagenous component of the organic matter of the Togur Formation in the study area varies in area and in the section (Kontorovich et al., 1995; Moskvin et al., 1999; Kostyreva et al., 2014). The distribution zones of kerogens II and III types were not characterized due to the insufficient amount of data and the assessment for each type was given separately.

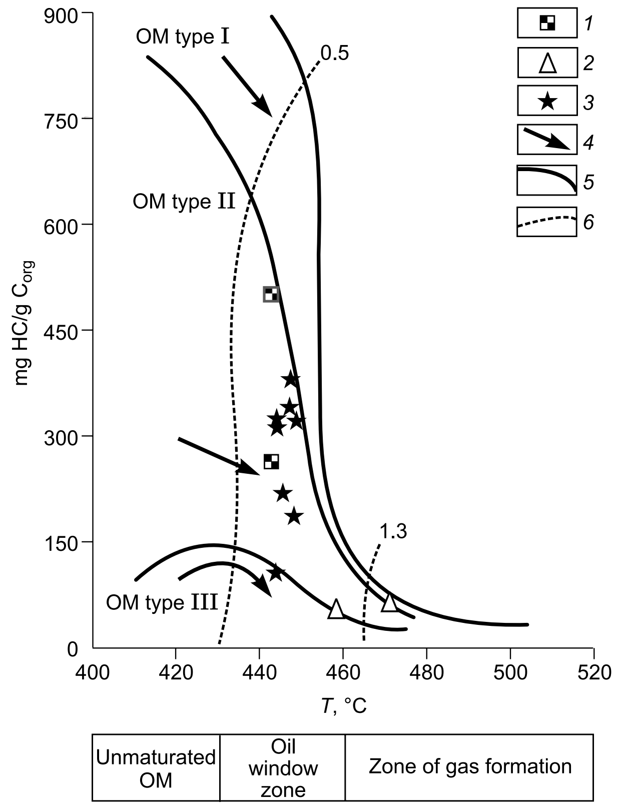

Fig. 4. HI–T_{max} diagram of the Togur Formation (based on the materials of Kim N.). *1–3*, rock samples from wells: *1*, Kiev-Eganskaya-211, *2*, Tolparovskaya-2, *3*, Yuzhno-Pyzhinskaya-1; *4*, directivity of changes in HI and T_{max} in catagenesis; *5*, lines that limit maximum HI values for three types of agents (I, aquagenous lacustrine, II, aquagenous marine, III, terragenous, associated with higher terrestrial vegetation); *6*, vitrinite reflectance isolines (R^0_{vt}).

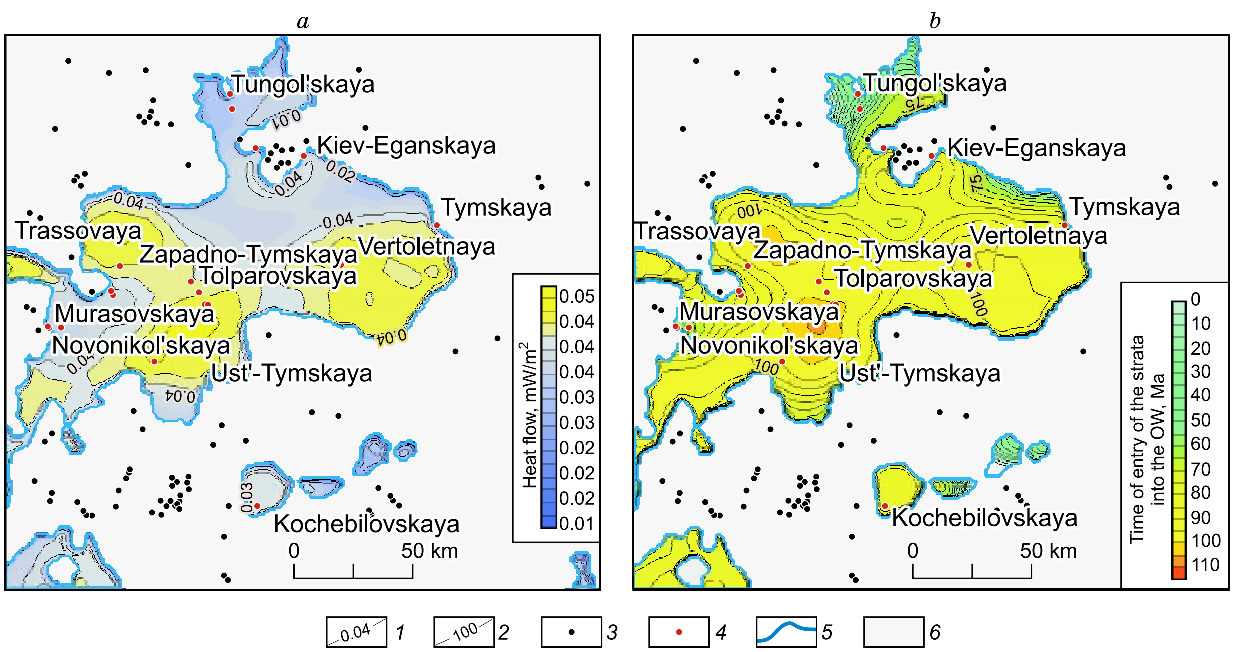

Fig. 5. Schematic maps of the heat flow at the boundary of the Earth's crust and upper mantle (*a*) and the time of entrance of the Togur Formation into the zone of oil window (R^0_{vt} = 0.60) in the Ust'-Tym sedimentary basin (*b*). *1*, isolines, mW/m²; *2*, isochrons, Ma; *3*, wells; *4*, wells in which the Hettangian–Aalenian deposits are discovered; *5*, boundary of distribution of the Togur Formation; *6*, zone of absence of Lower Jurassic deposits.

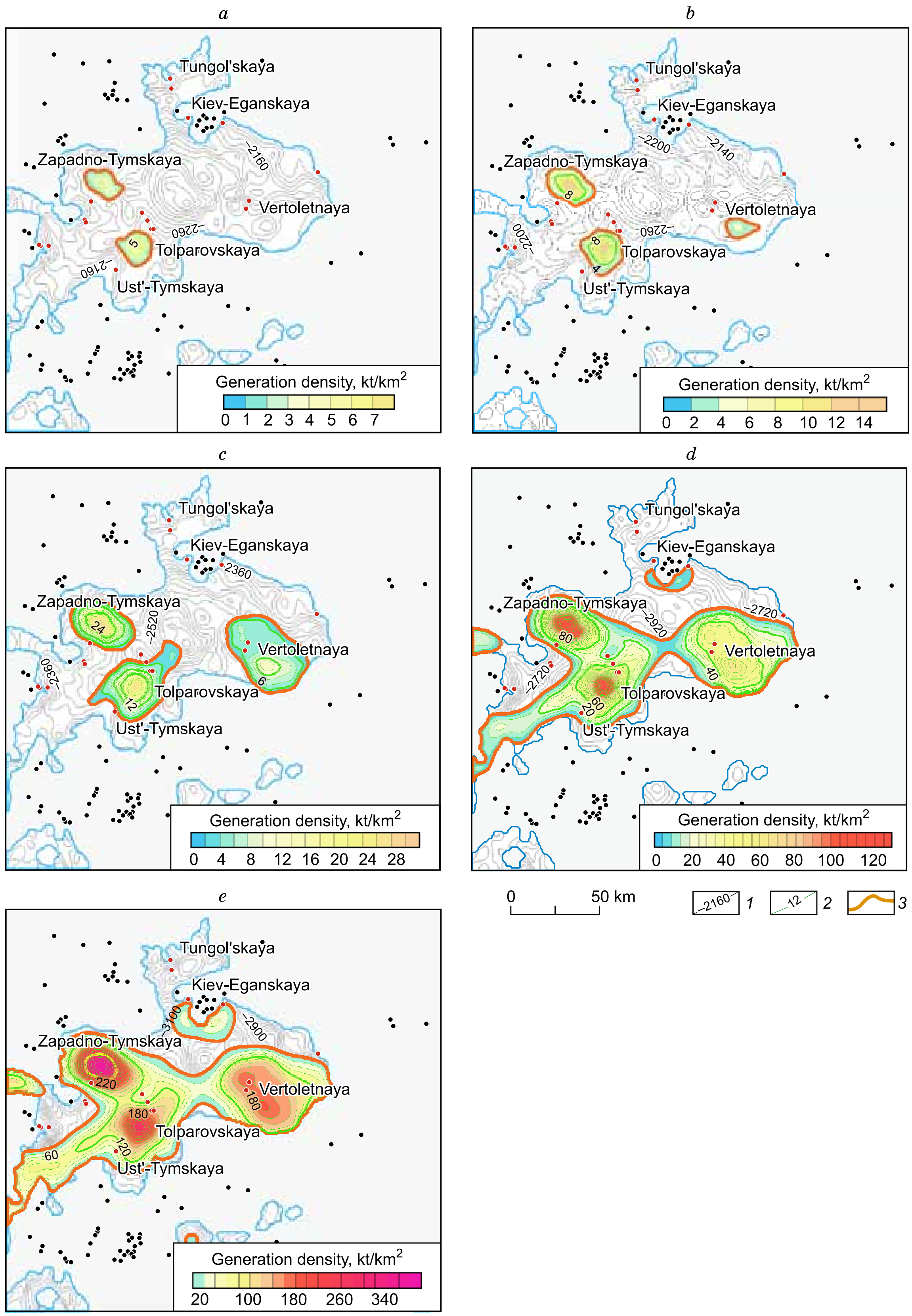

Fig. 6. Schematic maps of the scale of generation of liquid hydrocarbons by organic matter of the Togur Formation for type II kerogen in the Ust-Tym sedimentary basin at the time of deposits formation. *a*, Pokur (93.9 Ma); *b*, Kuznetsov (89.8 Ma); *c*, Ipatov (83.6 Ma); *d*, Talit (61.6 Ma); *e*, at present. *1*, isohypses; *2*, isolines, s.t./km^2; *3*, boundary of generation area; *4–6*, other symbols see in Fig. 5; *7*, pre-Jurassic basement.

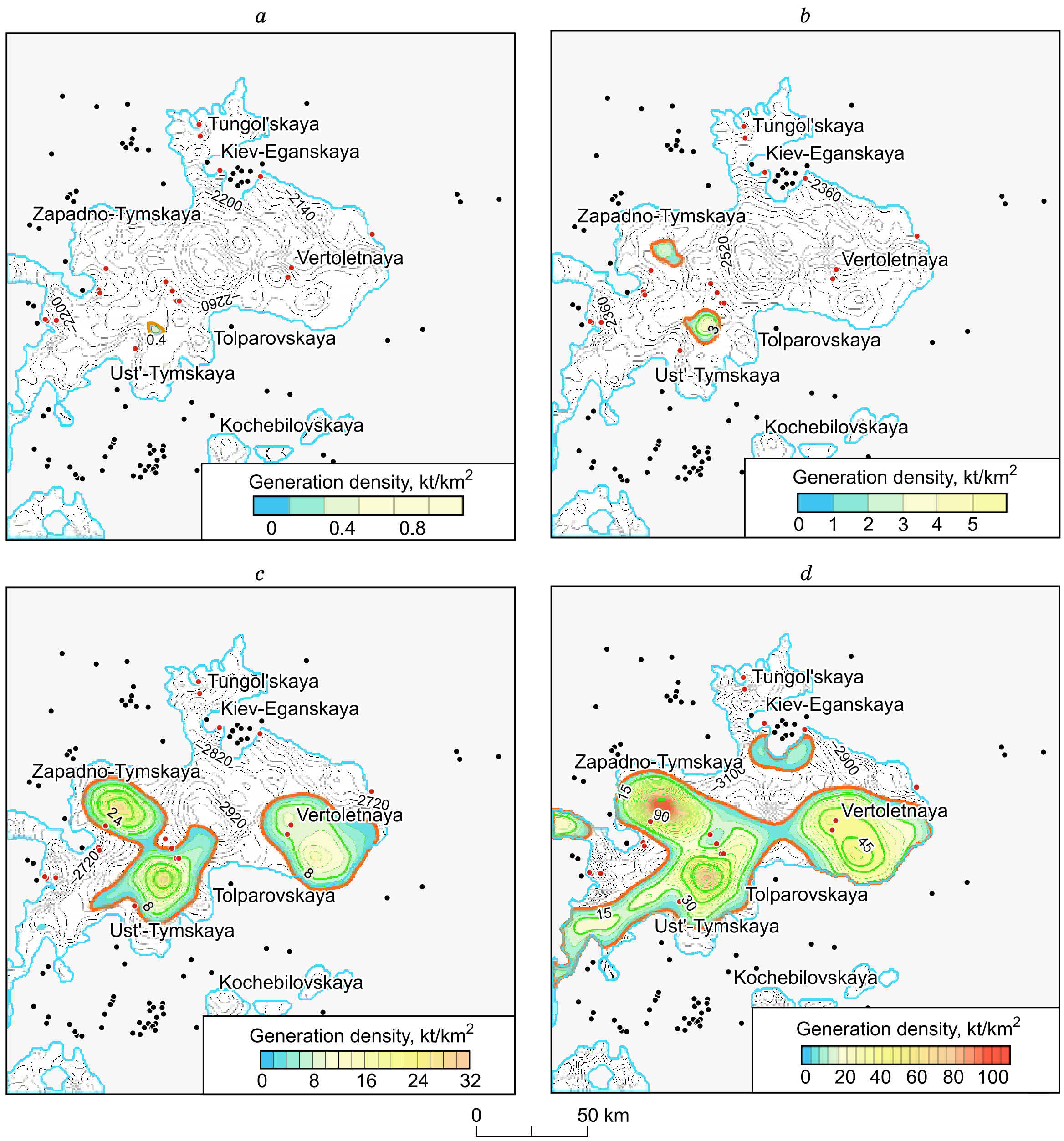

Fig. 7. Schematic maps of the scale of generation of liquid hydrocarbons by organic matter of the Togur Formation for type III kerogen in the Ust'-Tym sedimentary basin at the time of deposits formation: *a*, Kuznetsov (89.8 Ma); *b*, Ipatov (83.6 Ma); *c*, Talit (61.6 Ma); *d*, at present. See the legend on Figs. 5 and 6.

Calibration of the temperature history of sediments, based on the analysis of the distribution of the reflectivity values of vitrinite in the basal horizons of the Lower–Middle Jurassic (Kontorovich et al., 1967; Fomin, 2011), modern temperatures and heat flows, was carried out to correctly create a thermal model. The constructed model of effective heat flow at the boundary of the lithosphere showed good convergence of the calculated values of the reflectivity of vitrinite at the present moment of geological history and real measurements in the core of the wells. The maximum values of heat flow are reached in the areas of West-Tym, Tolparov and Vertolet areas (Fig. 5*a*) and are about 50 kW/m^2. Warming decreases in the direction of the Tungol area and in the most elevated areas.

Reconstruction of the history of the entry of the Togur Formation into the main zone of oil formation (OW) was carried out in the work. The beginning of the upper boundary of the OW corresponds to the reflectivity of vitrinite 0.6% (gradation of catagenesis MK_1^1), the lower limit 1.0% (stage II medium-catagenesis—MK_2) (Kontorovich and Melenevskii, 1988; Fomin, 2011).

As a result of computational experiments, we obtained maps of OM catagenesis, transformation of kerogen, time of entry of the Togur Formation into the main zone of oil formation, as well as maps of the scale of generation of liquid hydrocarbons.

Deposits of the Togur Formation began to subside into the main zone of oil formation at about 115–110 Ma (at the end of the Aptian) in the most depressed parts of the Ust'-Tym megadepression (Tolparov and West-Tym areas). Rocks in the side parts of the megadepression entered the oil window about 5 Ma (Pliocene) (Fig. 5*b*). The exit of rocks from the OW began about 48 Ma (early Eocene) in the West-Tym, Tolparov and Vertolet areas and continues to the present.

The modern content map of C_{org} was used to reconstruct the generation history (Kontorovich et al., 2018). The distribution of the initial concentrations of the C_{org} of the Togur Formation was restored taking into account the thickness of the clay strata and the total thickness of the complexes. The history of the generation of liquid hydrocarbons was recovered for II (Fig. 6) and III (Fig. 7) 7 types of kerogen.

The generation of liquid hydrocarbons by kerogen II began in the Upper Cretaceous (approximately 94 Ma) in the most submerged parts of the Ust'-Tym megadepression, in the area of the West-Tym and Tolparov areas. The generation area (S_g) was 526.6 km^2, the generation density (ρ_g) did not exceed 7 thousand tons/km^2 at the time of accumulation of the Pokur Formation (Cenomanian). Type III kerogen did not generate hydrocarbons at this stage, oil shows were not found.

The generation area (S_g) for type II kerogen expanded to 1000 km^2 (generation processes begin within the Vertolet area), ρ_g of oil increased to 14 thousand tons/km^2 in the Turonian (89.8 Ma, at the time of accumulation of the Kuznetsov Formation). For type III kerogen, the first minor demonstrations of oil formation occur in the West-Tym area (S_g = 34 km^2, ρ_g does not exceed 1 thousand tons/km^2).

By the end of the Late Cretaceous (83.6 Ma, at the time of accumulation of the Ipatov Formation, Santonian), there was a further increase in the density and scale of generation of liquid hydrocarbons. For type II kerogen, S_g = 3241 km^2, ρ_g = 30 thousand tons/ km^2, for III, the generation process began on the West-Tym area, S_g = 283 km^2, $\rho_g \leq 5$ thousand tons/km^2.

In the early Paleocene (61.6 Ma, at the time of accumulation of the Talit Formation, Danian–Selandian), the generation processes began to take place more actively, for type II, S_g = 7235.4 km^2, ρ_g reached 130 thousand tons/km^2 (Tolparov area). For type III kerogen, S_g expanded to 4156.2 km^2, ρ_g increased to 30 thousand tons/km^2.

Currently, S_g = 8903.5 km^2 for type II, ρg reaches 420 thousand tons/km^2, S_g for type III increased to 7604 km^2, ρ_g reached about 110 thousand tons/km^2 with the highest values on the Tolparov, West-Tym and Vertolet areas. Despite the active generation processes for types II and III, they do not occupy the entire area of distribution of the source rock; we can assume a further increase in the scale and density of generation.

For the II and III types of kerogen, the volumes of liquid hydrocarbons generated during the Mesozoic–Cenozoic history with a constant time step of 5 million years were calculated. The dynamics of generation processes in time is shown in diagrams (Fig. 8). Volumes of hydrocarbon generation by organic matter increase with time, increasing volumes occur now. For type II kerogen, generation began about 110 Ma (Aptian–Albian), for type III—90 Ma (Upper Cretaceous). The maximum volumes of generated HC occur in the last 5 million years and amount to 1.2×10^6 m^3 (type II) and 0.26×10^6 m^3 (type III).

For Hettangian–Aalenian deposits, maps of petroleum potential show the scale of generation of liquid hydrocarbons at present (Fig. 9).

An oil deposit on the Tolparov area, 5 promising objects and an aquifer in the Tym area were identified in the Het-

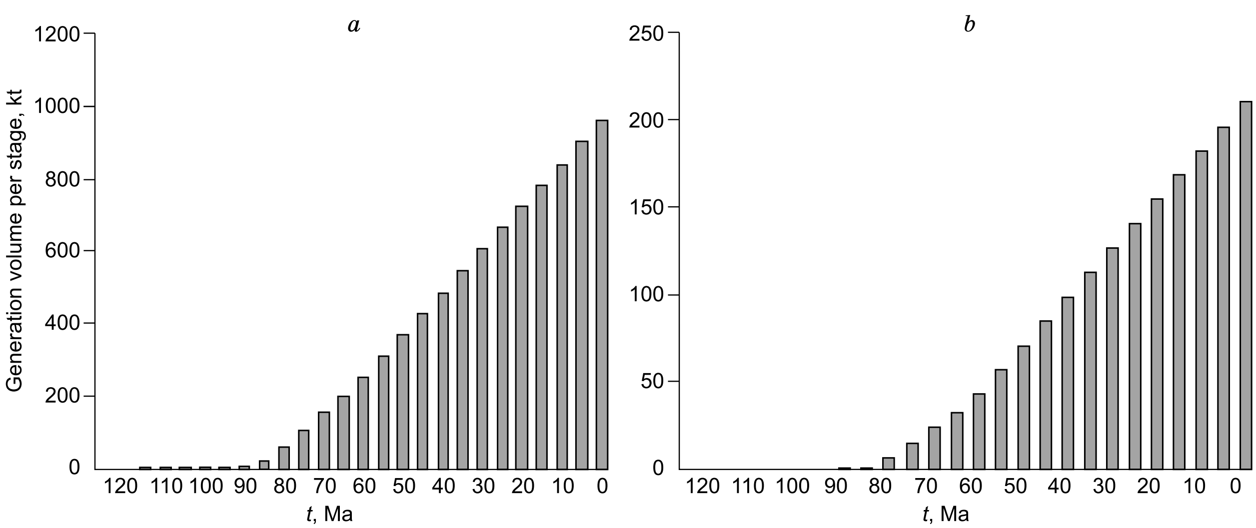

Fig. 8. Diagrams of the generation of liquid hydrocarbons by the organic matter of the Togur Formation for type II kerogen (*a*) and type III kerogen (*b*) over time.

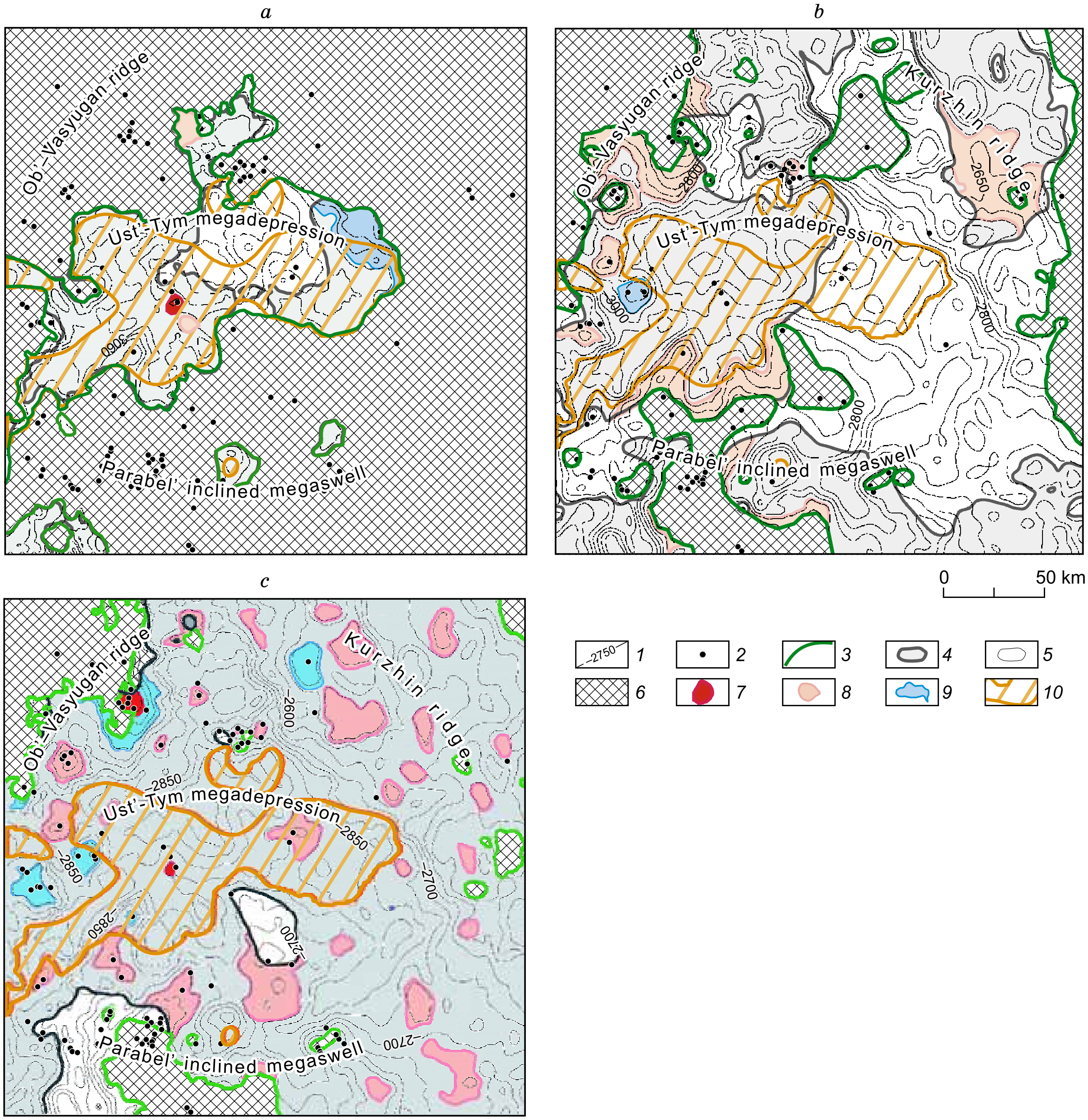

Fig. 9. Petroleum potential maps of the subcomplexes: *A*, Hettangian–Early Toarcian (U_{16-17}); *B*, Toarcian–Aalenian (U_{15}); *C*, Aalenian (U_{11-14}). *1*, isohypses, m; *2*, wells; *3*, sediment boundary; *4*, reservoir distribution area; *5*, reservoir absence zone; *6*, pre-Jurassic basement; *7*, hydrocarbon accumulations; *8*, perspective objects; *9*, aquifers; *10*, generation zone of liquid hydrocarbon.

tangian–Early Toarcian subcomplex (U_{16-17}). In the Toarcian–Aalenian subcomplex (U_{15}), 11 promising objects and 1 aquifer in Murasov area were identified. In the Aalenian subcomplex (U_{11-14}) the following deposits are identified: oil in Tolparov area and gas and oil in the Vartov area, 30 promising objects and 5 aquifers. In total, there are 3 hydrocarbon deposits, 46 prospective objects and 7 aquifers in the Hettangian–Aalenian oil and gas complex.

CONCLUSIONS

The Ust'-Tym megadepression and adjacent positive structures were formed actively in the Jurassic time. As a result of multidirectional regional tectonic movements that took place in the Cretaceous and Cenozoic, the structures were finally formed in the post-Turonian–Cenozoic time. The formation of local uplifts occurred throughout the Mesozoic–Cenozoic, but these processes were most intense in the Jurassic and the Early Cretaceous.

The Togur Formation is the main oil source rock in continental Jurassic sediments. It began to enter the main zone of oil formation 115–110 Ma and remains in the OW to the present. The generation of liquid hydrocarbons of type II by kerogen began about 110 Ma, and type III by kerogen—90 Ma. By the time of intensive petroleum generation, anticline structures, potential traps for hydrocarbon deposits, already existed in the Hettangian–Aalenian complex and could accumulate hydrocarbon deposits.

According to the results of basin modeling, the total volumes of liquid hydrocarbons generated by the aquagenous (type II kerogen) and mixed (type III kerogen) organic matter of the Togur Formation were 794,580 thousand tons and 173,020 thousand tons respectively. At present, the generation of hydrocarbons in the Lower Jurassic oil-producing thickness has reached the maximum level. At the same time, a comparison of the estimated D_0 oil resources in the Hettangian–Aalenian complex traps (104,960 thousand tons) with the volumes of generated hydrocarbons suggests that the existing generation volumes are sufficient for oil deposits to form in many of the selected traps.

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