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Facies variability of pennsylvanian oil-saturated carbonate rocks (constraints from Bashkirian reservoirs of the south-east Tatarstan)

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Abstract. One of the strategic ways of the old oil-producing regions is to further prospecting for potentially promising areas for hydrocarbon. One of these exploration areas is the Volga-Ural region. These reservoirs consist of Carboniferous carbonate rocks, which contain high viscous hydrocarbons and are characterized by complex facies architecture and reservoir properties influenced by diagenesis. The high degree of facies variability in the studied area does not allow reliable distribution of potential reservoir rocks not only between different areas but even within the same oil field. Based on textural and compositional features of carbonate facies, 5 main facies associations were identified and characterized with respect to the depositional settings in the Bashkirian basin. The facies associations correspond to: distal middle ramp facies, open marine proximal middle ramp facies, high-energy innershoal facies, inner ramp facies of restricted lagoons, facies of affected by subaerial exposures. From west to east in the study the following trends in facies character are identified: 1) a decrease open marine middle ramp facies and in the total thickness of the Bashkirian sections; 2) an increase in evidences of sub aerial exposures; 3) a decrease in the proportion of potential reservoir rocks. A general shallowing of the depositional setting was identified in an eastward direction, where potentially promising reservoir facies of shallow high-energy environments were replaced by facies of restricted lagoon and facies affected by subaerial exposures and meteoric diagenesis (palaeosols, dissolution). The applied approach based on detailed carbonate facies analysis allows predicting the distribution of potentially promising cross-sections within the region.

Keywords: Bashkirian stage, carbonate ramp, facies, reservoirs, correlation

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Introduction

Currently, the prospects for oil production are becoming increasingly important in the Volga-Ural region, which includes the southeastern part of Tatarstan. The main reasons are deposit inundation of clastic reservoirs and involvement in the development of deposits with unconventional resources (bitumen deposits and black shale formations of the Domanic type).

At the same time, according to the authors, small attention is paid to carbonate reservoirs, as objects that have significant prospects of oil production and can ensure the region's energy stability soon.

These reservoirs include regionally oil-bearing carbonate rocks of the Bashkirian stage. The difficulty of their exploration lies in the high facies variability of reservoir rocks in the studied area and the difficulty of correlating of facies from section to section.

Attempts to correlate using different methods for comparing sections were carried out by various authors (Mukhametshin, 1982; Kochneva, Koskov, 2013; Galkin, Efimov, 2015; Kolchugin, Morozov et al., 2013, etc.). The authors used correlation techniques based on a statistical analysis of deposits, comparing data from geophysical well surveys, where the core analysis of the studied sections was not assigned the most significant role. The authors of this article believe that the lithological and facial principle of comparing sections based on core analysis and should be the basis for the correlation of deposits in the area. Such an approach will allow qualitatively dissecting the studied sections and established the all variety of

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lithotypes which composing the sections and the laws of their change both vertically (along the section) and horizontally (over the area).

The object was core material selected from Middle Carboniferous units from the Bashkirian strata. The sections were studied from the most fully represented core wells since drilling of the Bashkirian section is often incompletely and is limited only to the productive zone. The studied core characterized deposits located on a line from west to east from deposits on the eastern side of the Melekesskaya depression to deposits located within the South Tatar anticline (Fig. 1).

The boundaries of the Bashkirian strata were detected according to GIS data. Also, the upper boundary is reliably detected by core analysis: by changing of Bashkirian limestones to carbonate-clayish strata of the Verey horizon (Moscovian), as well as by changing fossils (Khalymbadzha, 1962; Khvorova, 1958).

The thicknesses of the Bashkirian sections of the studied area on average 40 meters, however, there is a general tendency to decrease (with minor variations) the thicknesses of the sections in the direction from west to east: from the eastern side of the Melekesskaya depression to the South Tatar anticline. Thus, the thickness of the studied Bashkirian sections varied from 60 to 18 meters. On the western slope of the South Tatar anticline, the volume of the studied sections is formed by the successions of the Kamsky horizon and the Cheremshansky horizon. Horizons unconformity cover the Serpukhovian strata. In the top of sections, the Bashkirian strata are unconformity overlap by Moscowian strata (Geology of Tatarstan, 2003).

It is believed that the sections of the Melekesskaya depression are more complete. In the Upper Bashkir section is detected the Melekessky horizon, up to 12 m thick, covers the Cheremshansky horizon (Geology of Tatarstan, 2003). However, the occurrence of the Melekessky horizon is noted in sections of the axial part of the Melekesskaya depression and it is possible on the eastern side of depression thickness may be less or they may completely disappear. In practice, horizons are not distinguished, which is caused by small volumes of paleontological studies and difficulties in comparing fragments of the section according to well log data. Traces of regional unconformity of rocks found in the sections. There are brecciated limestones and the loss of a certain group of fossils, according to V.S. Gubareva (Gubareva et al., 1982). In industry special studies of fossils are practically not provided.

The authors propose a methodology for identifying patterns of variability and correlation of deposits, based on the allocation and tracking of facies in the area. One of the ways based on a qualitative description of core material and analysis of petrographic sections. The practical side of the study is the possibility of using the proposed methodology to track potentially promising reservoir rocks by area and, conversely, to identify low promising areas.

Research methods and study methods

Macroscopic study of core samples

The studied sections were characterized by continuously selected core material with an actual core yield of 90-100%. This allowed the authors qualitative

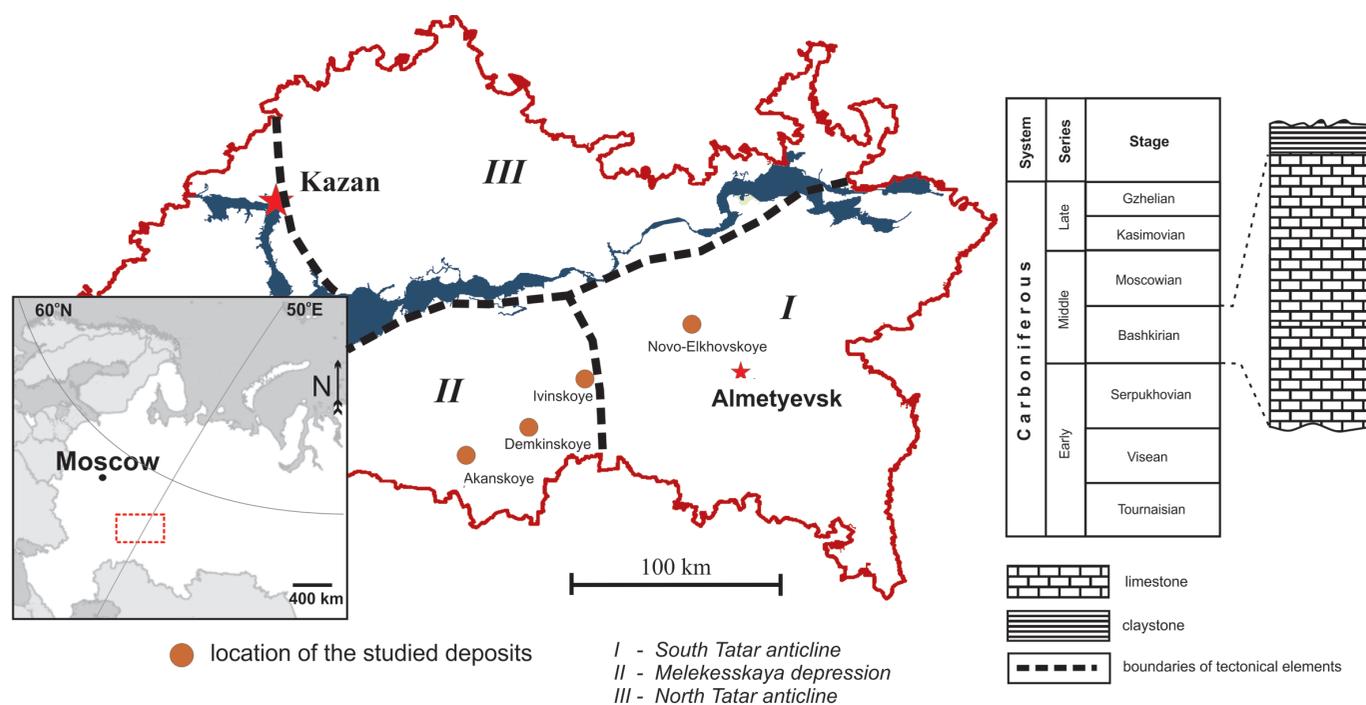


Fig. 1. The location scheme of the studied deposits, the main tectonic elements of the region, and a brief lithological and stratigraphic characteristic of the Carboniferous system

describe the sections and selected in detail rock samples for research. Work with the core material began from preliminary sawing along the axis. It is necessary for a qualitative description and identification of structural and textural characteristics of the rock, fluid saturation, and other features. The description was from bottom to top along the section. Such an approach allows us to reliably establish the patterns of change of rock types under the conditions of the Bashkirian sea: variation in the depth of the basin, intraformational erosion, subaerial exposures, etc. Special focus was paid to the relationship of lithotypes, lithological and paleontological composition, structural and textural features of the rocks. Samples were selected with step from 30 to 70 cm, depending on the facial variability and fluid saturation of rocks

Optical microscopic studies

Petrographical analysis of thin sections was made using an Axio Imager A2 polarizing microscope. Analysis of the thin sections included determination of the mineral composition, identification of the microtexture and structure of the rocks, fossil fragments, determination of facies. The structural classification of Dunham (Dunham, 1962) was chosen as a classification of carbonates, used by the international community and most of the oil companies in Russia, in recent years.

The methodology of lithological and facial reconstructions

The lithofacies model was used to determine the type of facies of allocated lithotypes. This model

of distribution of facies determines the presence of lithotypes in various physical and geographical settings. They are controlled by the morphology of coastline, changes in the depth of the water basin, the topography of the seafloor, distance from land, etc. Distribution of facies has a certain pattern, in conditions of increasing depths of basin. The authors created a distribution scheme for the facies of the Bashkirian sea for the studied area (Fig. 2), based on the analysis of several models of marine carbonate precipitation (Immenhauser et al., 2004; Della Porta et al., 2004). Latin letters are used: A, B, C, D, E, for the convenience of detected facies. Detailed interpretation of the facies will be done in the “Results” part.

Results

Bashkirian successions were formed in the conditions of gentle slope carbonate ramp, based on analysis of the composition of the rocks (Proust et al., 1998). Precipitation of carbonates was in normal marine environments of low latitudes (Kolchugin, Immenhauser et al., 2016). The studied region can be defined as a transition zone between the inner and middle ramp with typical carbonate sedimentation (Kolchugin, Della Porta et al., 2017). The authors proposed to distinguish 5 main types of facies, which differ in the lithological and paleontological composition.

Facies A is limestone, represented by skeletal packstones, rarely wackestone with an abundance of fragments of brachiopods and spines, crinoids, benthic foraminifera, and peloids (Fig. 3A), fragments of corals.

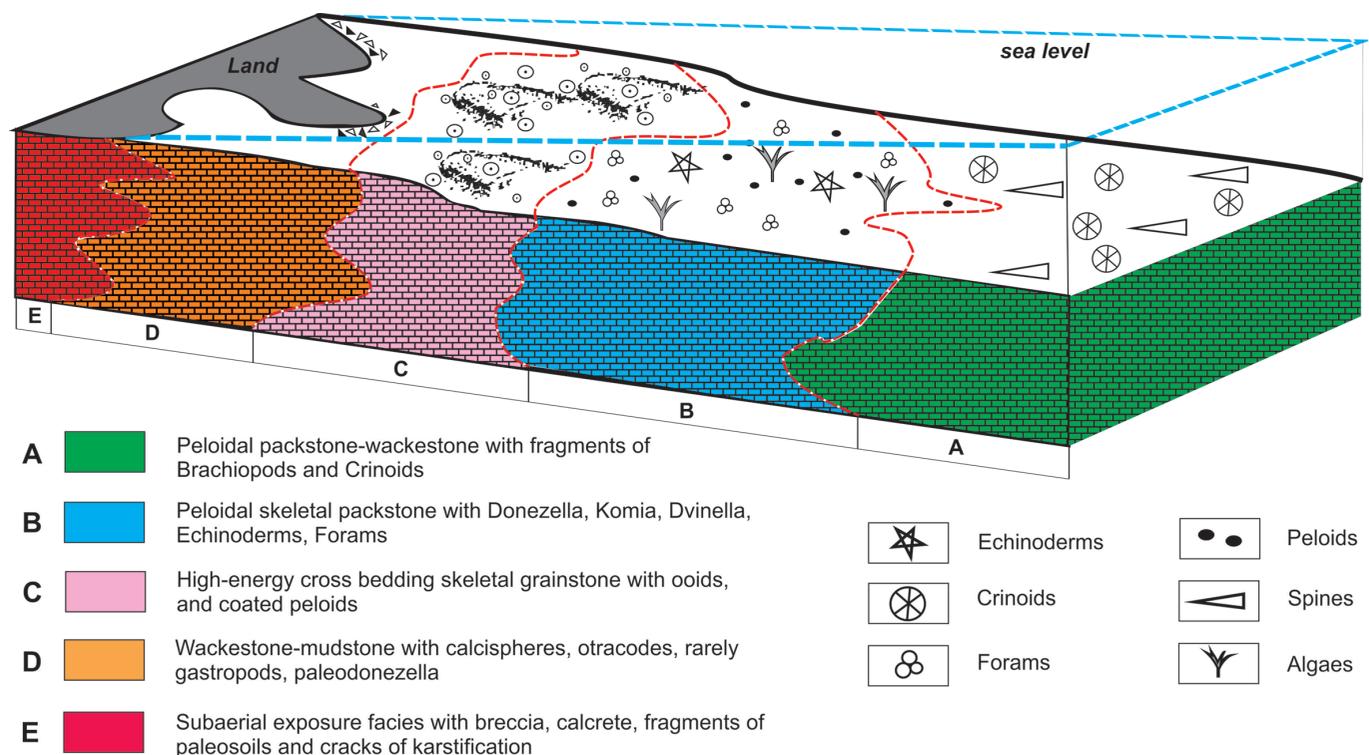


Fig. 2. The main groups of Bashkirian facies



Photos of thin sections in normal light of the main type of facies

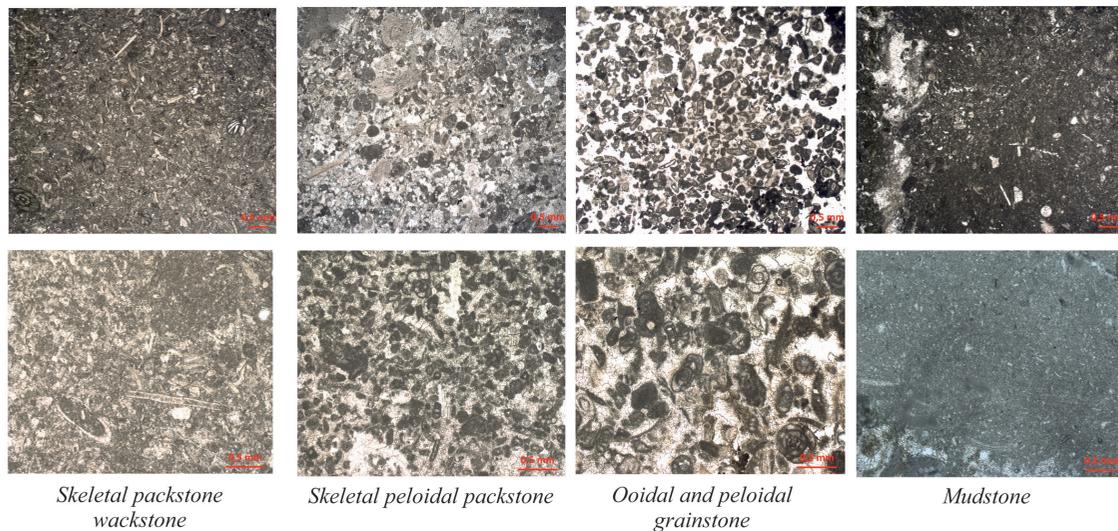


Fig. 3. Photos of samples and thin sections in the normal light of the main identified facies, as an example of limestones of the Ivinsky deposit. The distribution and composition of the facies are shown in the legend to Fig. 2.

Facies B is represented by skeletal peloid packstones, sometimes by grainstones with an abundance of benthic foraminifera (*Glovivalvulina*, *Climacammina*, *Dvinellalovilvulina*, *Climacammina*, *Bradyina*), fragments of echinoderms and bryozoans (Fig. 3B).

Facies C is represented by well-sorted grainstones, with crossed lamination with an abundance of ooids, bioclasts, and fragments of various grains and intraclasts. The facies is characterized by the intergrain type of porosity, isopahous rims of marine fibrous cement (Fig. 3C).

Facies D is represented by mudstones (Fig. 3D) and wackstones with rare grains of peloids, calcispheres, beresellidealgae gastropods, and ostracods.

Facies E is composed of various types of limestones: breccias (Fig. 4A), mudstones and wackstones, sometimes bundstones (Fig. 4B), and packstones. All facies have traces of secondary iron mineralization and recrystallization. Rocks are often characterized by the

presence of sediment or cracks of karstification (Fig. 4C) with fragments of subaerial leaching and fragments of paleosols and calcrete. Breccias are often characterized by the black pebbles (Fig. 4A).

The authors selected the most typical sections which are characterizing the eastern side of the Melekesskaya depression and the Western slope of the South Tatar anticline and analysis of the variability of rocks in the studied area. One of the most western sections is the section of the Bashkirian strata of the Akansky deposit, located on the eastern side of the Melekesskaya depression. The Novo-Elkhovsky deposit was selected as the most eastern section in the studied area. A significant number of sections were studied, between "opposite" sections on the line from west to east. However, sections of Ivinsky and Demkinsky deposits were chosen as the model between the selected, since they were best characterized by core samples (Fig. 5). It was possible to give a detailed description of the

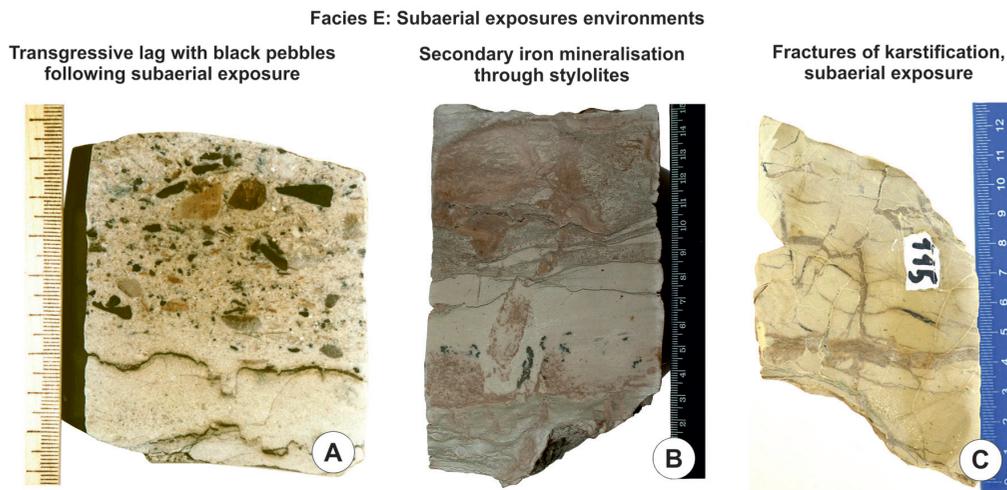


Fig. 4. Photo of samples of facies E. Example of samples with traces of subaerial exposures of Novo-Elkhovskoye (A) and Ivinsky deposits (B, C). A – carbonate breccia, B – Mudstone-boundstone with iron mineralization, C – Mudstone with cracks of karstification and iron mineralization, filled by clay minerals.

types of rocks and establish the boundaries of change lithotypes.

An important feature of all studied sections is the presence of traces of subaerial exposures. In sections, they are marked as facies E and highlighted in red. The proportion of facies E varies from section to section and generally increases from west to east. Another feature is a decrease in the total thickness of the Bashkirian sections. The thickness of the deposits is 45-60 m on the eastern side of the Melekesskaya depression and does not exceed 20-25 m on the western slope of the South Tatar anticline.

Discussion

The variability of the Bashkirian successions from west to east mostly caused by more intraformational erosion of strata within the western slope of the South Tatar anticline. This is indicated by an increasing share of brecciated limestones in sections, traces of subaerial exposures, and meteoric diagenesis. This type of diagenesis has often explained the lack of effective porosity in grainstones, which seem to be the most promising rocks as potential reservoirs. The pore space of such grainstones is almost filled by early diagenetic calcite. The periodic outbreak of rocks above sea level takes a negative role in the preservation of primary high porosity. Meteoric waters change the physicochemical parameters of precipitation conditions and produce recrystallization of rocks and calcite cementation, filling of pore space by secondary calcite (Badiozmani, Mackenzie, 1977; Moore, 1989).

The presence of reddish colors of rocks indicates the periodic outbreak of rocks above sea level. It is caused by the appearance of iron oxides and hydroxides as markers of subaerial exposures (Fig. 4). Breccias contain black pebbles and found in sections of the western slope of

the South Tatar anticline. The black color of pebbles is caused by humic organic matter (fragments of ancient paleosols). This indicates a relatively long time of continental subcontinental environments where could form soils.

The Bashkirian basin is an epicontinental basin with extremely insignificant depth differences. Periodic glacioeustatic oscillations of the marine basin drained some areas. It led to the erosion of previously accumulated carbonates. Bashkirian time was a time of active fluctuations in sea level and produced by global glaciation (Bishop, Montañez et al., 2009; Mii, Grossman et al., 2001).

Probably, glacioeustatic oscillations were a key factor in sea-level change. Traces of erosion are captured only in the form of thin brecciated limestones, in the western sections. In the eastern sections are limestones with traces of secondary iron mineralization, limestones with polygonal cracks of the early stages of karstification, and meteoric type of diagenesis, in addition to brecciated limestones (Fig. 4). It indicates relatively deeper marine environments in the west of the studied region (the modern eastern side of the Melekesskaya depression) and more shallow in the east (modern western slope of the South Tatar anticline). Moreover, the authors do not exclude that even more characteristic tracers could simply be eroded of the existence of rocks in subaerial exposures and changing of sea level.

Correlation of sections between deposits difficult task, because of the high degree of facial variability in the studied area. However, such correlation is quite realistic based on the frequency of certain facies and the patterns of their change along the section, as well as the tracking of intervals of subaerial exposures (Fig. 5). It seems that the intervals of subaerial exposures can be considered as some benchmarks for the correlation of

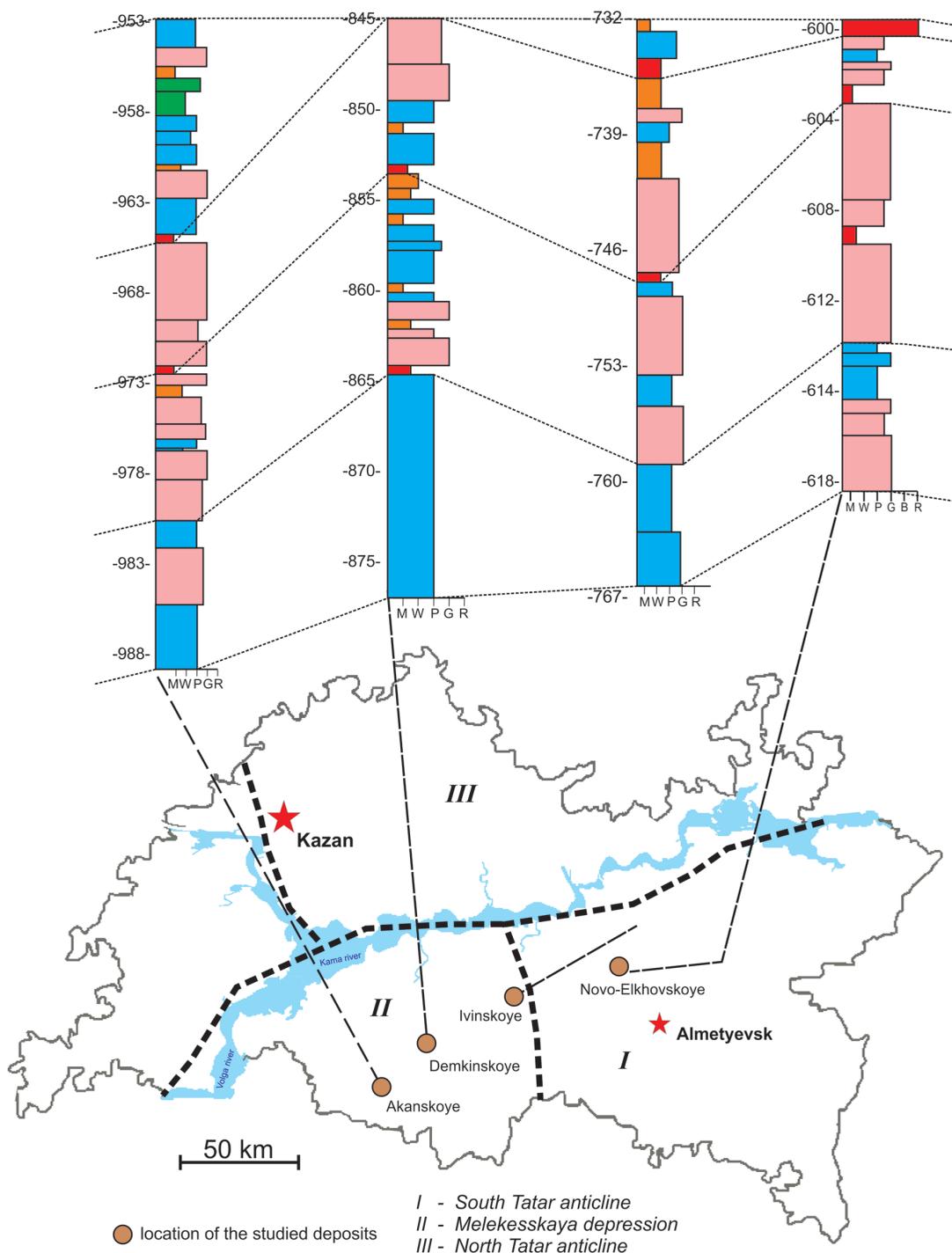


Fig. 5. The position of the studied sections on the profile from west to east. The sections show the distribution of selected facies. The color of the facies is shown in Fig. 2.

sections. Studying the Bashkirian sections shows that all the sections have at least two intervals of subaerial exposures in the middle and upper parts of the sections. Probably, they were the most obvious stages of subaerial environments. It can find a larger number of such intervals in the eastern sections, located on the western slope of the South Tatar anticline. It caused by more shallow marine environments of carbonate precipitation. Moreover, such “regional breaks” of sedimentation are well distinguished in sections and can be used to compare strata.

It is noted variability in productivity and oil saturation, in addition to facies changes within the selected profile from west to east. First of all, this is connected with the potential reservoir rocks represented by packstones and grainstones, which are thinning to the east. If the packstones almost disappear in the eastern sections, grainstones lose porosity in conditions of subaerial diagenesis. The industrial production of such sections is lost, and often rocks do not have any signs of oil saturation.

Conclusions

An analysis of the composition of the studied sections and the position of the sections studied area allowed to draw several conclusions.

1. It is observed a decrease in the share of normal marine environments from the west (the eastern side of the Melekesskaya depression) to the east (the western slope of the South Tatar anticline), at the same time, an increase in the share of restricted lagoon facies and subaerial exposures. In the same direction is observed a general decrease in the thickness of the Bashkirian sections.

2. It is reduced the industrial productivity of sections and the overall oil saturation of the rocks from west to east in the studied area. This is due to two main factors: 1) it is lithological and facies composition of the section, due to a decrease in the share of potential reservoir rocks (packstones and grainstones); 2) it is the type of diagenesis of carbonate sediments, where potentially promising reservoir properties of rocks were lost under the subaerial conditions and the influence of meteoric diagenesis.

3. The high facies variability of the Bashkirian strata caused by global glacioeustatic sea-level fluctuations, and the amplitude of which sea-level change could be up to several tens of meters. In this case, a significant part of sections could be thinning (up to 10-15 m) due to erosion.

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