CARACTERÍSTICAS PALEOFACIAIS DO TOPO DA FORMAÇÃO ROCHOSA POKURSKAYA DENTRO DE TRINCHEIRA PURSKIY

PALEOFACIAL CHARACTERISTIC OF UPPER PART OF THE POKURSK SUITE WITHIN THE PURSKY DEFLECTION

ПАЛЕОФАЦИАЛЬНАЯ ХАРАКТЕРИСТИКА ВЕРХНЕЙ ЧАСТИ ПОКУРСКОЙ СВИТЫ В ПРЕДЕЛАХ ПУРСКОГО ПРОГИБА

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RESUMO

Nas últimas décadas, uma tendência de aumento da parte dos depósitos de hidrocarbonetos caracterizados por uma estrutura geológica muito complexa tem sido bem observada. A solução de problemas geológicos para este tipo de geo-objetos exige urgentemente uma abordagem integrada ao processamento e interpretação das informações primárias disponíveis (diretas, indiretas, a priori), aumentando a precisão e adequação dos modelos geológicos e geofísicos. O desenvolvimento constante de sistemas de software integrados permite melhorar a qualidade dos modelos geológicos conceituais, aplicar técnicas multivariadas de modelagem geológica tridimensional. Eventualmente, tudo isso leva a um aumento na precisão e no detalhamento das ideias sobre as características da estrutura geológica dos corpos geológicos em estudo.

Palavras-chave: *depósitos, correlação, horizonte de reflexão, cubo sísmico, análise de fácies sísmica.*

ABSTRACT

In recent decades, there is a tendency of increasing the share of deposits of hydrocarbons, characterized by a complex geological structure. Solving geological problems for this type of geo object requires a comprehensive approach to processing and interpreting the available primary information (direct, indirect, a priori), increasing the accuracy and adequacy of geological and geophysical models. Constant development of integrated software systems allows improving the quality of conceptual geological models, to apply multivariate techniques of three-dimensional geological modeling. In the final analysis, all this leads to an increase in the accuracy and detail of the notions of the features of the geological structures of the geological bodies under study.

Keywords: *sediments, correlation, reflecting horizon, seismic cube, seismic facies analysis.*

АННОТАЦИЯ

В последние десятилетия хорошо прослеживается тенденция увеличения доли залежей углеводородов, характеризующихся очень сложным геологическим строением. Решение геологических задач для такого типа геообъектов настоятельно требует комплексного подхода к обработке и интерпретации имеющейся первичной информации (прямой, косвенной, априорной), повышения точности и адекватности геолого-геофизических моделей. Постоянное развитие интегрированных программных комплексов позволяет улучшить качество концептуальных геологических моделей, применять многовариантные методики трехмерного геологического моделирования. В конечном счете все это приводит к повышению точности и детальности представлений об особенностях геологического строения исследуемых геологических тел.

Ключевые слова: *отложения, корреляция, отражающий горизонт, сейсмический куб, сейсмофациальный анализ.*

INTRODUCTION

Within the Pursky Deflection, the productivity of the Cenomanian sediments is related to the regionally productive reservoir of PC_1. The PC_1 layer is characterized by cover spreading and developed in sand facies throughout the study area. The cover for the reservoir is the aged Turonian clays of the Kuznetsov suite. The roofing of the reservoir according to the GIS data is repelled unequivocally and does not cause doubts. Correlation of the base of the formation (Dallmeyer et al., 1995), due to the massive structure of the reservoir and the absence of aged clay packs, is quite arbitrary. Figure 1 shows a diagram of the cross-well correlation in the reservoir interval PC_1.

According to the early 2000 model, the PC_1 formation is divided into two layers. The division of the formation is based on the result of a detailed correlation, performed on a facies basis. The lower layer (PC $layer_1^2$) is a complex built-up sediment of the coastal lake-alluvial plain. The top layer (PC $layer_1^1$) was formed in shallow water at the initial stage of the transgression, which replaced the continental conditions, and is blocked by deep-sea sediments of the Turonian age. The two main layers are separated by a silty-clay, which is permeable in places.

In the wave seismic field, the roof of the reservoir PC_1 is controlled by a reflecting horizon (RH) "G". As an auxiliary, the additional RH "Gpod" exhaust gas, traced near the bottom of the PC_1 formation, has been correlated. At the level of the upper layer of PC_1^1, a sufficiently consistent reflection corresponding to the positive phase RH "G" of the exhaust gas can be traced. Bottom sediments, the continental portion of the formation PC_1 (PC_1^2) in the wave field is displayed with more complications (Wei and Su, 2015). Features of the wave pattern inherent in this interval of the cut are related both to the effect of the gas reservoir of the PC_1 layer, and to the abundance of numerous erosion cuts (Figure 2).

MATERIALS AND METHODS

The most important primary source of information for any geological work is the core. Only by studying the core a geological model can be properly compiled, petrophysical properties of rocks and geophysical characteristics attached to it. A core in the area study in the range reservoir PC_1 characterized borehole drilling № 606 (the upper interlayer PC_1^1). The analysis of the core material showed that in the upper part of the reservoir PC_1 a shallow-marine type of sediments is developed. Analysis of the core and the results of the interpretation of the GIS in the lower part of the reservoir PC_1 indicates the possible development of delta and (below) channel sediments (Bogatireva *et al.*, 2012; Gladysheva, 2012; Lin *et al.*, 2007).

In conditions of acute core material deficiency, the basis of the facial analysis of Cenomanian deposits is the well-known technique of V.S. Muromtsev (1984), based on the determination of genetic features of rocks by electrometric cuts of wells. The PC (GK) curves were compared with typical electrometric models of facies and determined their belonging to one or another genetic group of deposits (Veeken and van Moerkerken, 2014). The paragenetic connections of the facies were taken into account, which makes it possible, in determining one or more of them, to assume the presence of others (Onajite, 2014; Holz *et al.*, 2017).

In the course of the analysis, a summary table of the electrometric models of facies of the reservoir PC_1 was compiled, which reflects their probable facial interpretation (Figure 3).

RESULTS AND DISCUSSION:

3.1. Lithological and facial characteristics of reservoir deposits PC_1

As noted above, in the section of the reservoir PC_1, two layers are distinguished (the layer of PC_1^1 and PC_1^2), differing in their structure, genesis and, accordingly, the distribution of clay and aleuritic-sandy material. If the formation conditions of the upper layer of formation PC_1 are not in doubt, then the model of the sedimentation environment of the underlying rocks (PC $layer_1^2$) has been refined, mainly due to the appearance of 3D survey data. The lower layer (PC $layer_1^2$) in the formation of PC_1 is a complexly built thickness of the alluvial-delta complex of sediments. Delta deposits form in different conditions and are composed of various sediments – from continental to marine inclusive. Schematically, the delta formation is presented in Figure 4.

Within the area of the study, the paleogeographic conditions of sedimentation of the PC $layer_1^2$ was a surface part of the delta. It should be noted that in the surface parts of the delta complex conditions prevail that are close in their hydrodynamic features to the conditions for the formation of alluvial facies (Budkin *et al.*, 2012; Dunaev and Zotov, 2016; Zhuravleva *et al.*, 2018). This, in turn, affected the incompletely accurate determination of the genesis of the deposits of the lower layer of the reservoir PC_1.

Deposits of the facies group of the above-water plain of the delta complex are formed on the site where the main river bed splits into several smaller delta channels and ducts. A significant place in the area and in the section is occupied by floodplain deposits (interchannel sands and floodplain clays, buried soils, sediments of lakes and marshes). Floodplain facies (area of wells No. 130R and 74R) are encountered by islands among riverbed channel facies (between channels). The sand bodies formed in the delta channels have the form of gentle incisions elongated along the strike in the form of continuous, converging and diverging bands subparallel to the main channel of the river and at an angle to the shoreline. For all precipitates of this type, a sharp erosion contact with the underlying sediments is characteristic. The total thickness of the paleosulphur deposits is 25 m.

The sedimentological model of this group of facies is the alternation of facies of riverbed shallows of delta channels formed under conditions of high dynamics of water currents and the facies of the outer and inner parts of the floodplains that form in the calmer hydrodynamic situation of sedimentation in flooded areas of the delta in the periods of floods, with low activity of the sedimentation environment. This alternation of facies is a distinctive feature of the deposits of the above-water plain of the delta complex.

Figure 5 shows an example of a delta of the Volga. Within its limits, a region is distinguished, which can be considered as a modern analog of the investigated surface part of the delta (Figure 6).

The electrometric model of the described deposits is represented by an alternation of two types of anomalies in the PC curve. One of them, associated with the delta canal deposits, is similar to the anomaly characteristic of channel river banks located in the zone of negative deviations of the PC and having the form of a quadrangle. The second, associated with sediments of the inter-canal sections of the delta, is similar to the anomalies characteristic of the sediments of river floodplains.

Within the above-water plain of the delta complex, it is possible to distinguish axial parts of sand bodies confined to the deepest part of the erosion cut and possessing maximum thicknesses, for example, borehole sections No. 126R-17R; 77R-9R-132R-16R and others. The sand bodies formed in the delta channels fill the entire axial and adjacent parts of the channel incision. On either side of the axial part, the thickness of the sand body is gradually reduced (Zhu *et al.*, 2009). In the zones of wedging, the sand body can be split into several interlayers, which is gradually shrinking and is replaced by clay differences, form a peculiar dissection (or denticulation) of the sand body in its marginal parts (borehole. No. 79R, 919R, and 14R).

The description of the facies in the wells served as a starting point for studying sedimentation accumulation (Obukhovskaya and Kruchek, 2016), separation, and mapping of facial zones from seismic data.

3.2. Seimofacies analysis of deposits of reservoir PC_1

The seismic facies analysis assumes a detailed study of the features of the wave pattern in the interval of the studied formation on vertical time profiles and attribute maps. A joint analysis of the features of the form of recording and their mapping allows seismic facies to be visually identified, and then to identify and outline their areas (Makanova and Shiryaeva, 2012; Okpogo *et al.*, 2018). The search for informative attributes is not an easy task since it is necessary to determine those of them, which are mainly influenced by the studied formation, and not underlying or overlapping layers, which is inevitable due to the phenomenon of interference.

The largest lithological heterogeneity in the Cenomanian section is sandy bodies that fill alluvial canals. They have increased porosity and permeability, which sharply differ from the enclosing floodplain deposits. Due to their inherent complex shape, reliable mapping of these bodies (without the use of seismic data) with the existing network of wells is impossible.

The main contribution to the formation of the wave pattern below the reflected wave "G" is made by the delta deposits of the PC layer$_1^2$.

When comparing the results of facial analysis from GIS data to the seismic wave pattern (Khisamov *et al.*, 2013), two main types of seismic facies (SF) are identified: "floodplain zone" and "erosion cuts" (Nezhdanov, 2004; Zunde, 2016; Izotova *et al.*, 1993; Shilov and Jafarov, 2001). It should be noted that a rather complex wave pattern is displayed on high-frequency (resolved) cuts. In order to simplify the seismic record, a filtered cut class with "clipped" high frequencies and an aligned spectrum is obtained. As a result, the sections were made easier for the perception (Figure 7).

Seismic anomalies such as "erosion cut" are characterized by a trough shape, the presence of a diverse internal pattern that preserves the history of channel migration and limits the anomaly of the side zones. The side zones look like a sharp change in polarity, and/or a visible recording period, sometimes flexure-like inflections of the in-phase axis. There may also be short reflections from the surface of the inconsistency inclined inside the cut.

The presence of reflection from the bottom of the cut, which limits the erosion cut from below, is optional and depends on the composition of the underlying rocks. A common sign of the sole of seismic erosion of the erosion cut is stratigraphic disagreement with the underlying strata (Gabdullin *et al.*, 2014; Borodkin and Kurchikov, 2010; Borodkin *et al.*, 2008; Catuneanu *et al.*, 2009). The internal wave pattern of the described seismic facies can be completely different depending on the mutual occurrence of the geological bodies forming it and their boundaries.

The seismic facies of the floodplain is not as pronounced as the previous one. Its main feature is the presence of 2-3 parallel or weakly inclined phases of small amplitude. They are also unextended and very changeable in form, but in general, the wave pattern is more stable than the filling of the cuts. Recording, as a rule, is more high-frequency. Flood seismic facies are located between anomalies such as "erosion cut" and reflect the rhythmic interstratification of sandstones and clay rocks formed in the conditions of the outer and inner floodplains (Zeng *et al.*, 2013).

The next step was to determine the patterns of spatial distribution of deposits of a given genesis. To this end, along with the existing well data on the structure of the PC layer$_1^2$, several attributes and methods for analyzing the wave pattern have been tested.

The reference map for selecting a particular seismic attribute map was the resultant sedimentation accumulation map for the continental part of the reservoir PC_1 (sublayer PC_1^2). In the lower layer of the reservoir PC_1, a complex alluvial valley was identified and mapped over the seismic and GIS data set, represented by a combination of stripe, branching and converging sleeves of sandy channels and the surrounding floodplain areas (Figure 8). This facies map is the result of detailed investigations that are summarized by lithofacies characteristic of lower reservoir layer deposits PC_1, seismic facies analysis and other activities aimed at obtaining detailed digital geological model of the reservoir of productive deposits PC_1. Close attention was paid to the study of electrofacies in each well that opened the Cenomanian deposits.

The search for informative attributes was carried out primarily within the boundaries of a generalized seismic cube, and then a 2D survey was added. The horizontal slices (parallel RH "G") of the volumetric classification of seismic facies were the most informative for understanding the structure of the reservoir and the history of its formation. After testing, a cube of cosines of instant phases was selected for the calculation of seismic classes according to the variant of the mid-frequency cube, which is optimal for reducing noise and reducing the effect of the gas (Nezhdanov *et al.*, 2000). And if for the southern part of the cube the horizontal cuts are at the level of 36 ms down from the RH "G", then for the rest of the cube – at the level of 24 ms (Figure 9).

In Figure 9, from the general background, the classes 1-18 (yellow-green and orange-red) are distinguished into separate zones, differing quite sharply in the shape of the pulse from adjacent areas. The shape and spatial position of these zones allow us to associate them with the detachments of the channels from the surface part of the delta complex. When comparing the selected boundaries with time profiles and electric logs (PC curves), it was concluded that these bodies belonged to erosion cuts filled with sand material. In their composition, axial (rod) parts of the erosion cuts, corresponding mainly to seismic classes 1-5 (orange-red color), are isolated into an independent facial zone. Formation of the axial parts of the incisions took place in the deepest parts of the paleochannels, where high velocities of water currents existed, and, consequently, all the typical features of the facies composing them were most contrastively manifested. According to borehole data, the axial parts of the cutters have enhanced filtration-capacitive properties and effective thicknesses (borehole№ 132R, 126R, and 77R), which means that they are the most attractive in terms of development.

Surrounded channeled deposits of floodplain areas, usually represented mainly by clayey lacustrine-bog sediments (borehole No. 907R, 18R, 912R, 8R, and 905R).

After the most informative attributes were found within the boundaries of the 3D survey, a 2D seismic survey area was connected to the seismic facies analysis. Based on the results of the search for dynamic attributes within the 2D survey, it has been established that the best convergence with the class map already obtained and the maximum detail are the maps of the rms amplitudes over the cosine sections of the instant phases. It should be noted that for the entire study area it was not possible to select amplitudes at a single time in view of the significant difference in the wave pattern in different parts of the area. For the northern part of the area, a cosine map of the instantaneous phases was used at a time of 24 ms from the RH "G", for the central part – 34 ms, for the southern part – 38 ms downwards (Figure 10).

As a result, a sedimentation accumulation map was obtained for the surface part of the delta complex of the reservoir PC_1 (Figure 11).

In addition to the erosion inflows (alluvial canals) on the resulting facies model of sediments for the continental part of the reservoir PC_1, the areas of distribution of temporary streams (wells No. 900R and 122R), which are characterized by lower power, compared to alluvial channels, and a more fine-grained sediment composition (Chukhlantseva and Chernova, 2014). This is due to a decrease in the dynamic activity of water streams.

In the time sections of this type of sediment, the wave pattern is in many respects characteristic of erosive incision deposits (Figure 12). Therefore, to determine the spatial boundaries of the sediments of the temporary stream, along with the analysis of the wave pattern, electrometric sections of the wells were used, and also the planned configuration of such bodies was analyzed.

The resulting facies map is in many respects similar to its "prototype" (Figure 8). However, there are some differences. First of all, compared with the previous work within the boundaries of 3D-model there is a significant detailing in mapped objects. Some refinements of the spatial position of alluvial bodies within the 2D-model are related to the reduction of time sections of different seismic groups to a single phase characteristic of the wave field. As a result, all this led to a certain change in the notion of the formation of the lower layer of deposits PC_1.

CONCLUSIONS:

In the paleofacial identification of the deposits of the upper part of the Pokursk suite within the Pursky Deflection, a number of features were revealed:

1) according to borehole data, there are no obvious patterns of the area development of paleofacial complexes;

2) analysis of the wave pattern does not allow to adequately isolate and trace the paleofacial zones;

3) for the detailed study of the paleofacial zoning of deposits in the composition of the reservoir PC_1, it is necessary to involve the results of the dynamic analysis.

Thus, the clinoform model of the structure of the Berrias-Lower Augustian sediments of Western Siberia and the current state of exploration suggest the isolation of three large territories, the stratification of the section, within which it is expedient to produce, taking into account the characteristics of the oil geological structure (Kazanenkov *et al.*, 2014). The first area is connected with the zones of development of western-decline clinoforms. Almost all oil and gas deposits in the Berrias-Lower-Aptian sediments are concentrated here. The cut was constructed by alternating sandy-aleuritic beds of shallow-marine genesis and transgressive clay groups. For this territory, it is proposed to use seismic-facial complexes as the main stratums. The second is to the east of the first and extends to the edge. In this territory, it is also proposed to abandon the suite division and combine the strata into the Ust-Taz series. The third area is associated with the east-decline clinoforms; it extends from the western ridge to the axis of the Berrias-Early-Apt basin and is composed mainly of clay strata. Here the use of the former suite stratification is suggested.

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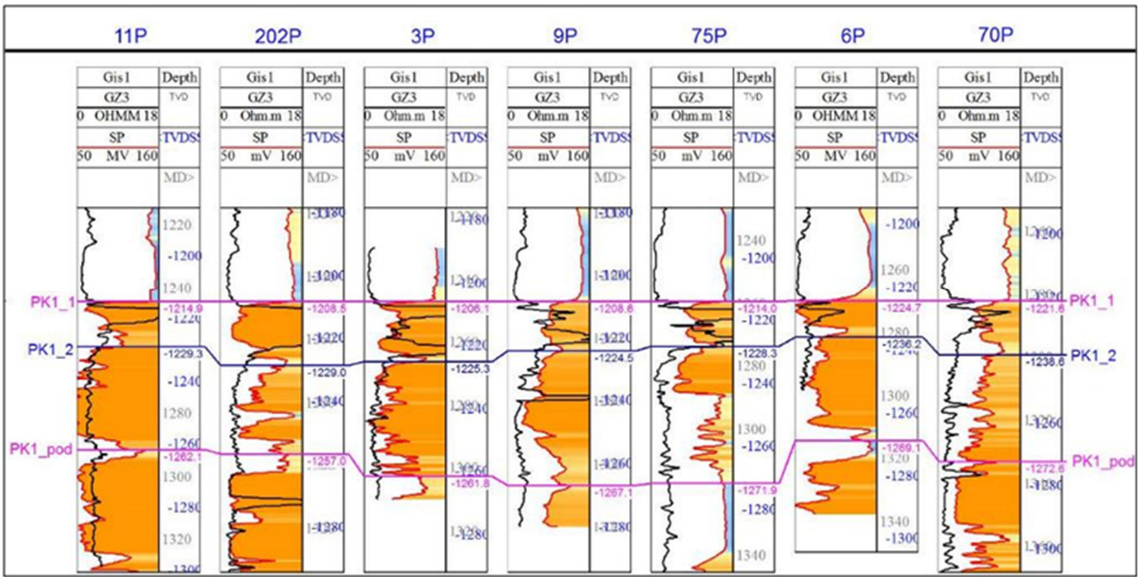


***Figure 1**. Scheme of correlation in the interval of formation PC_1*

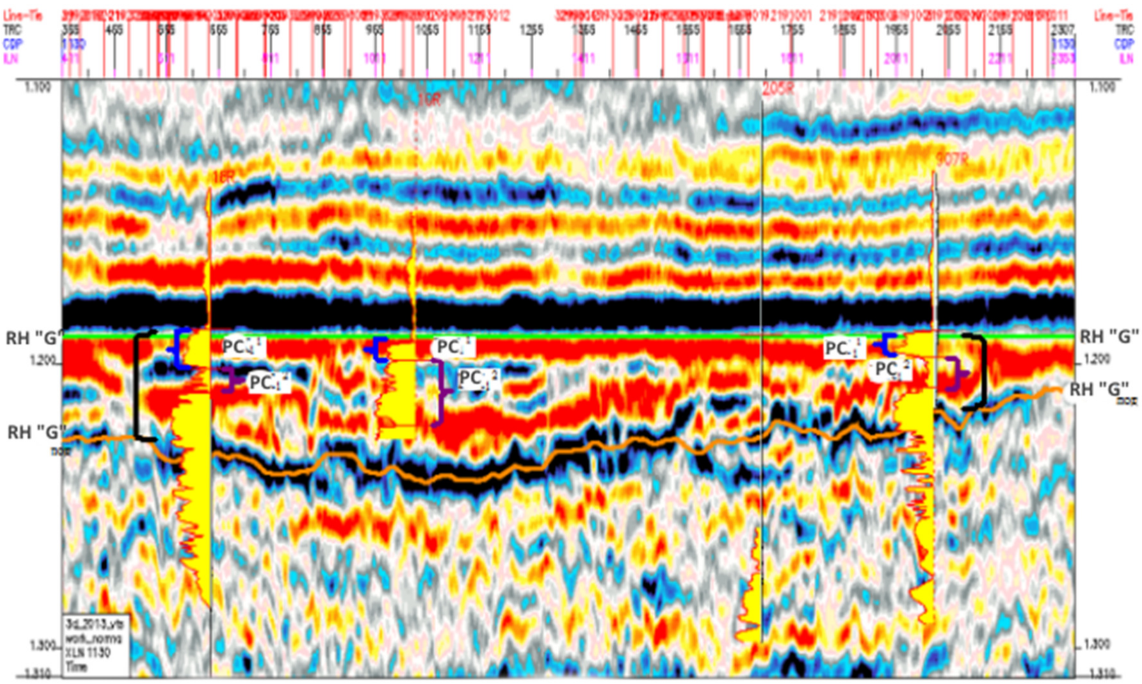


***Figure 2**. Typical vertical cross-section of the temporary cube*

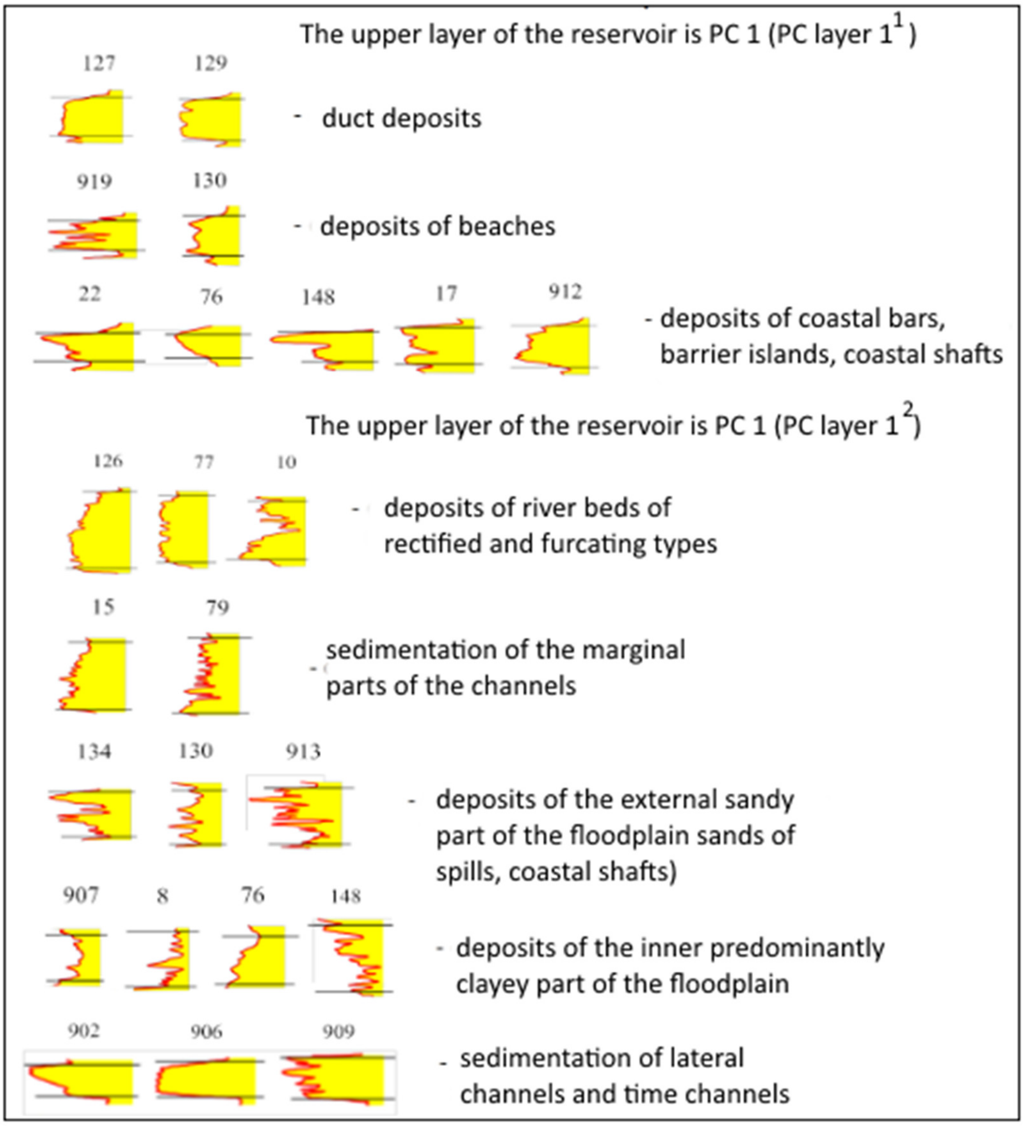


***Figure 3**. Electrometric models of facies of formation PC₁*

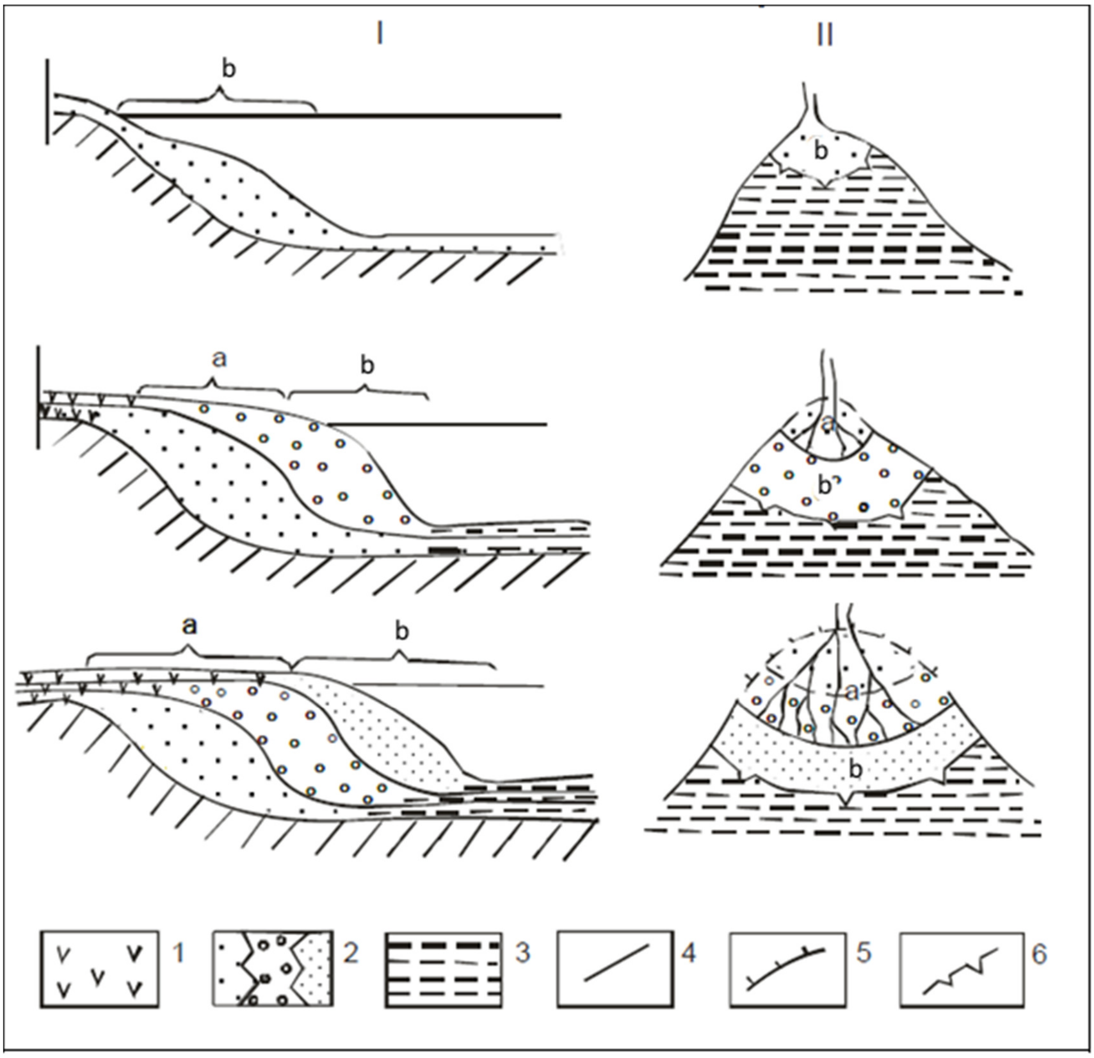


Figure 4. *Schematic diagram of delta formation with respect to a stable sea level in section (I) and in the plan (II), according to V.G. Kuznetsov and B.K. Proshlyakov (1991). Deposits: 1 – continental; 2 – deltas of various stages; 3 – sea; 4 – coastline; 5 – continental trending; 6 – external sea; a – the above-water part of the delta; b – underwater part of delta (advance delta)*

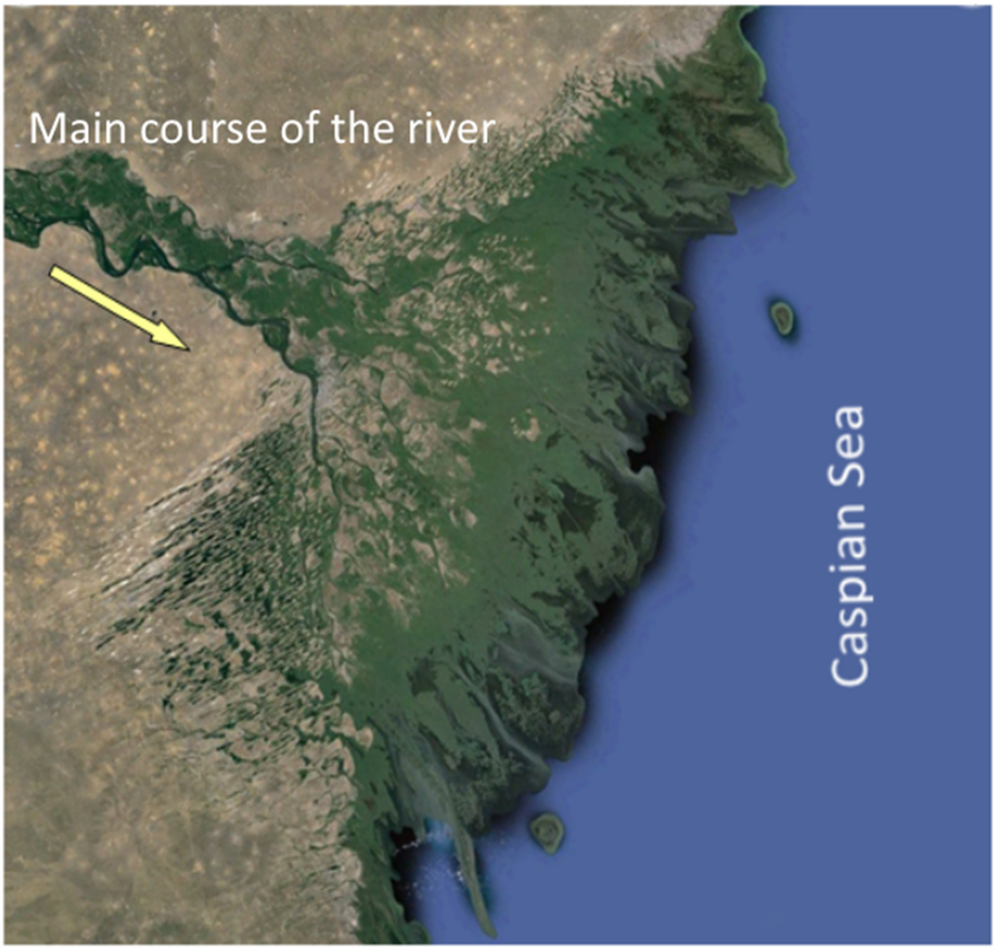
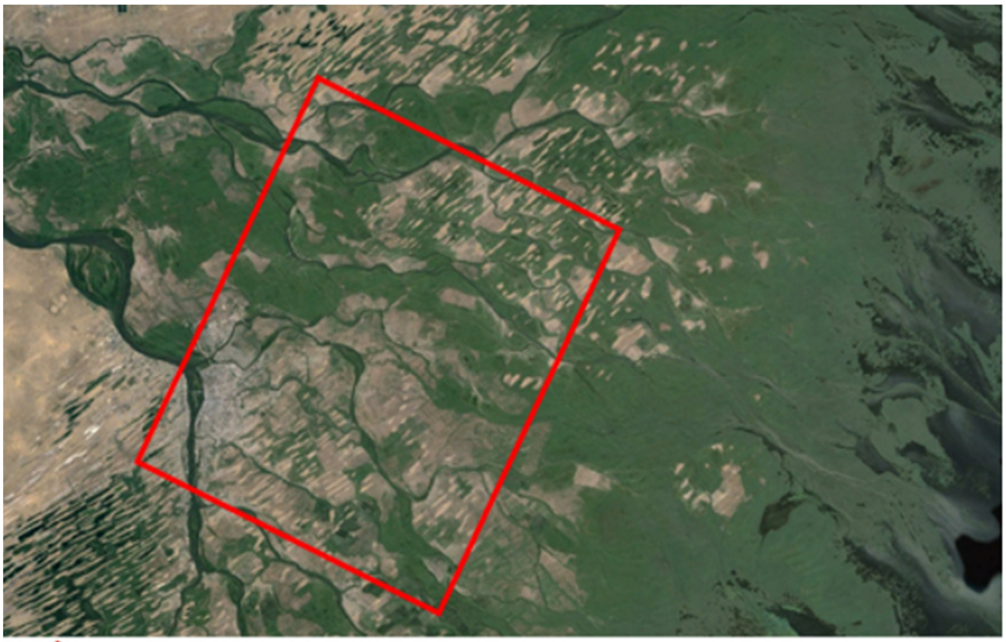


***Figure 5**. Picture of the delta of the Volga Delta, Astrakhan Region, Russia*



\- analogue of the paleogeographic zone at the time of formation of the lower layer of the PC 1 layer within the area of the study

***Figure 6**. Zoomed-up fragment of the above-water part of the Volga delta, Astrakhan*

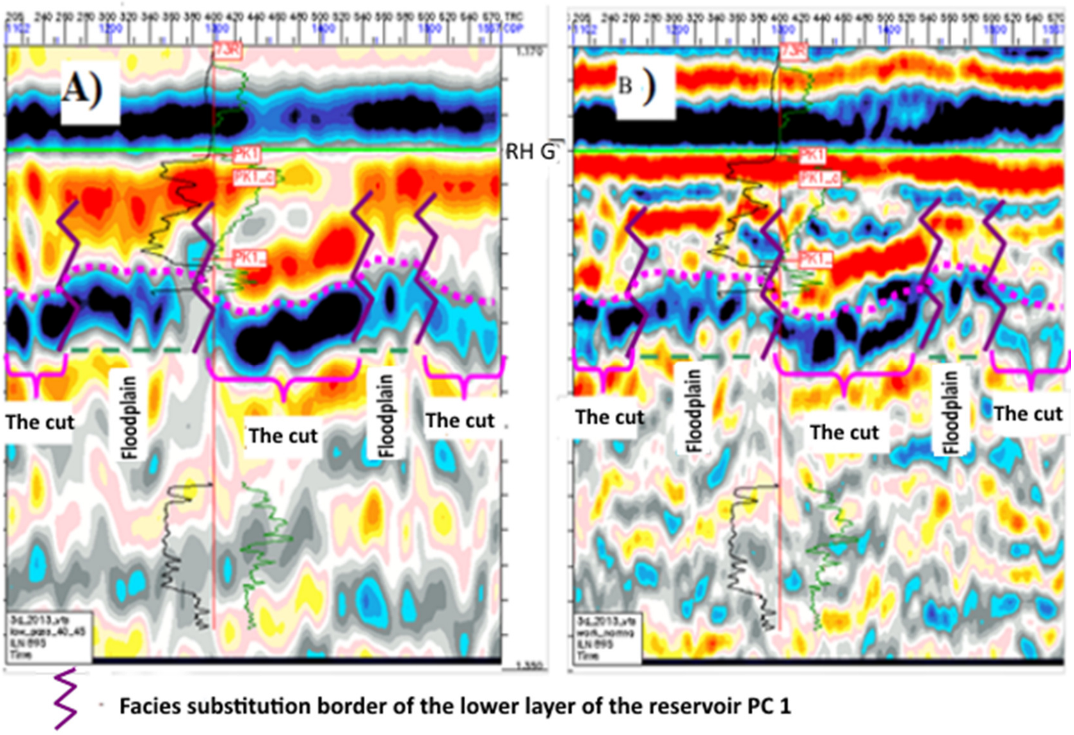


Figure 7*. Fragment of the time section: A – filtered cube with BCA; B – high-frequency cube with BCA*

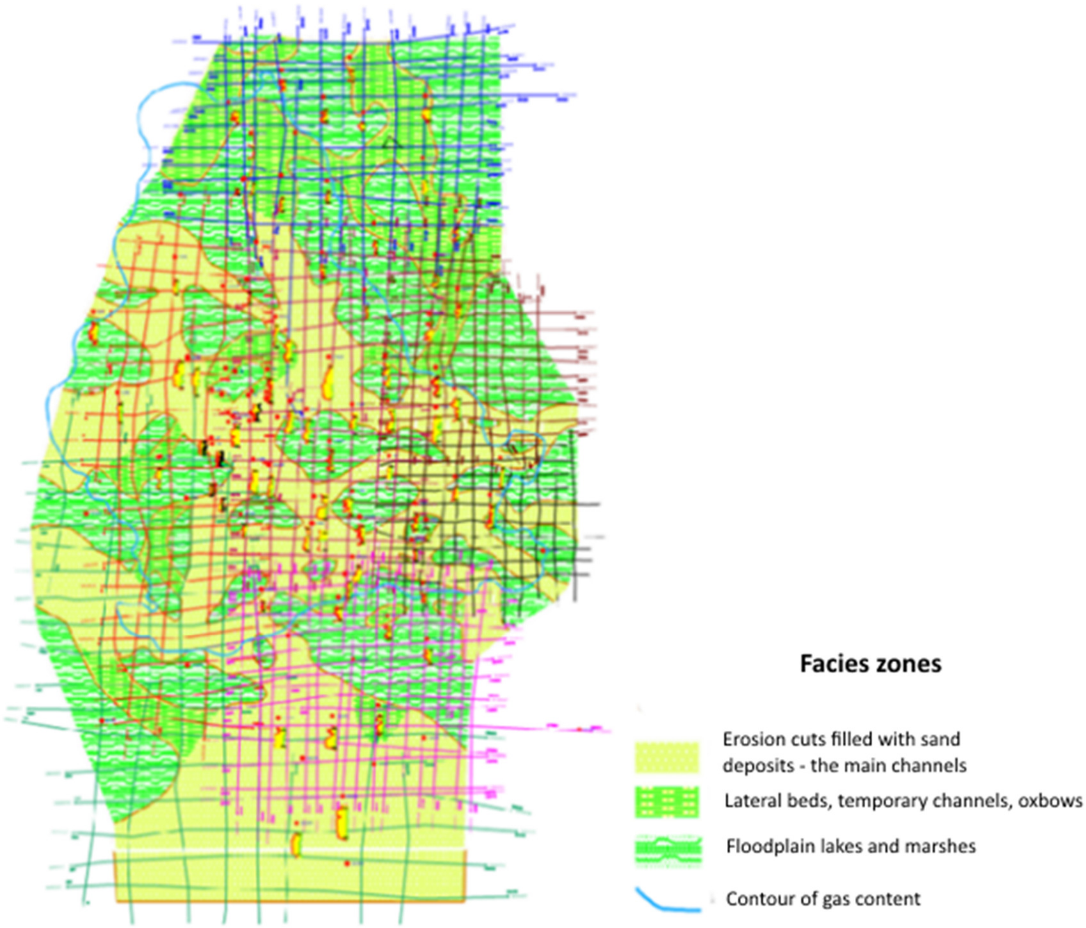


***Figure 8**. The map of sedimentation environments for the continental part of the reservoir PC_1*

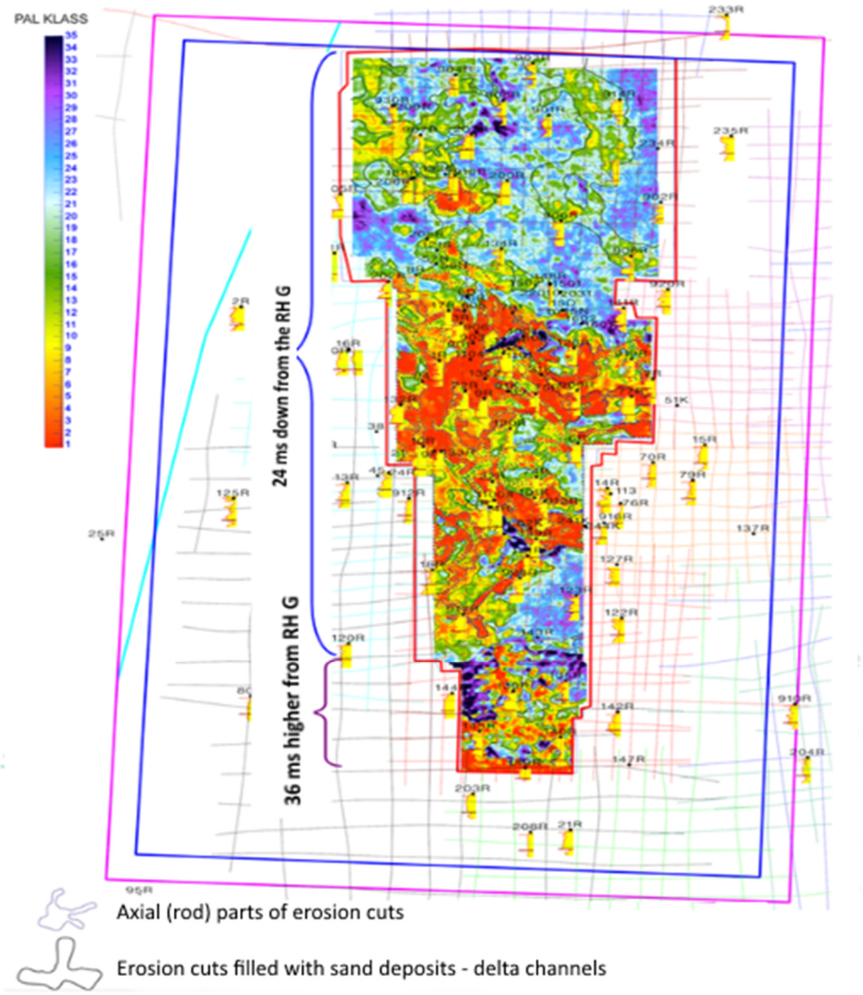


***Figure 9**. Horizontal sections by volume classification in the interval of the lower layer of the reservoir PC_1 (PC $layer_1^2$)*

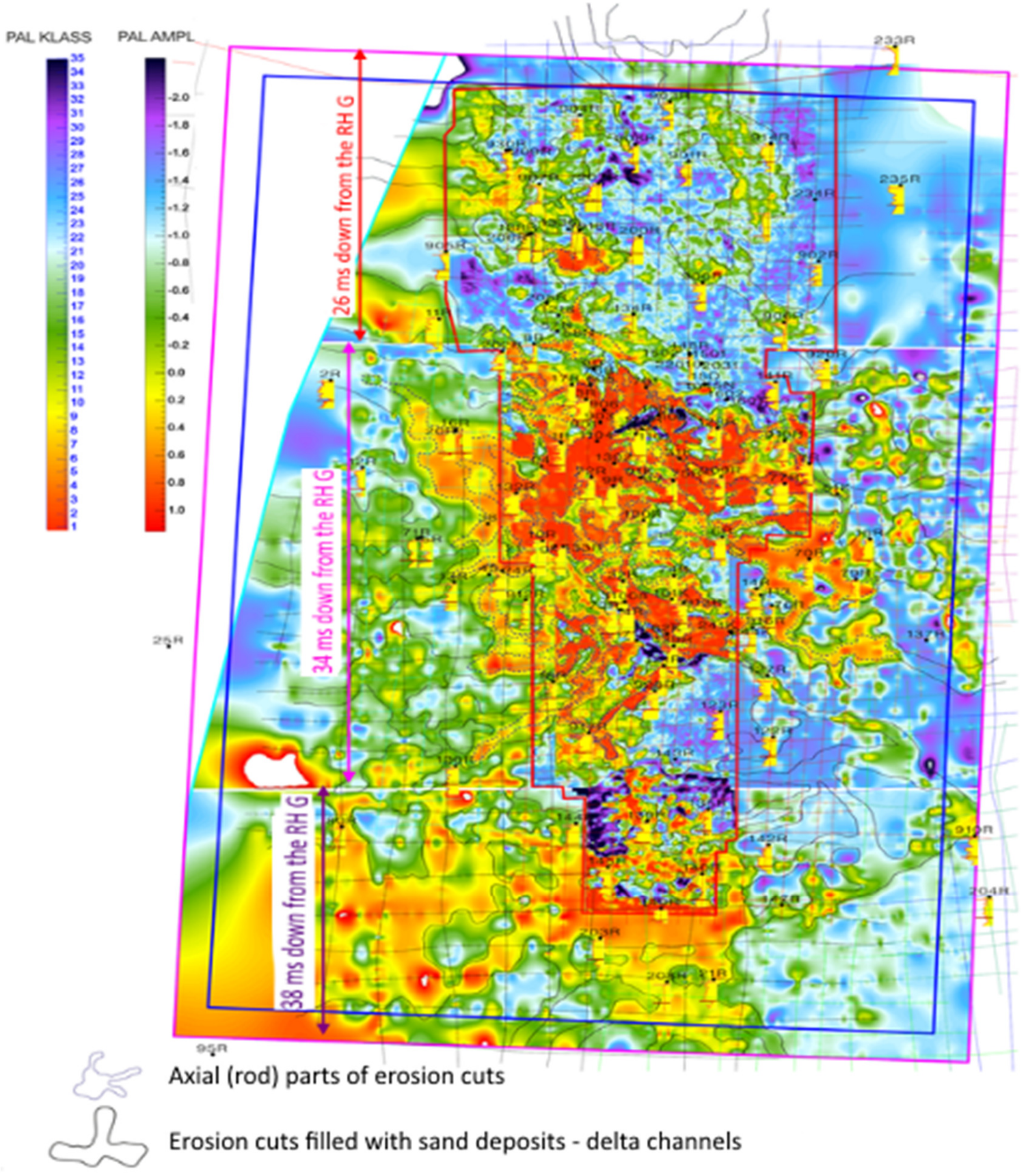


***Figure 10**. Mounting of amplitude maps by cuts of cosine instantaneous phase and the horizontal slice volume in the labeling interval of the formation of the lower layer PC_1 (sublayer PC_1^2)*

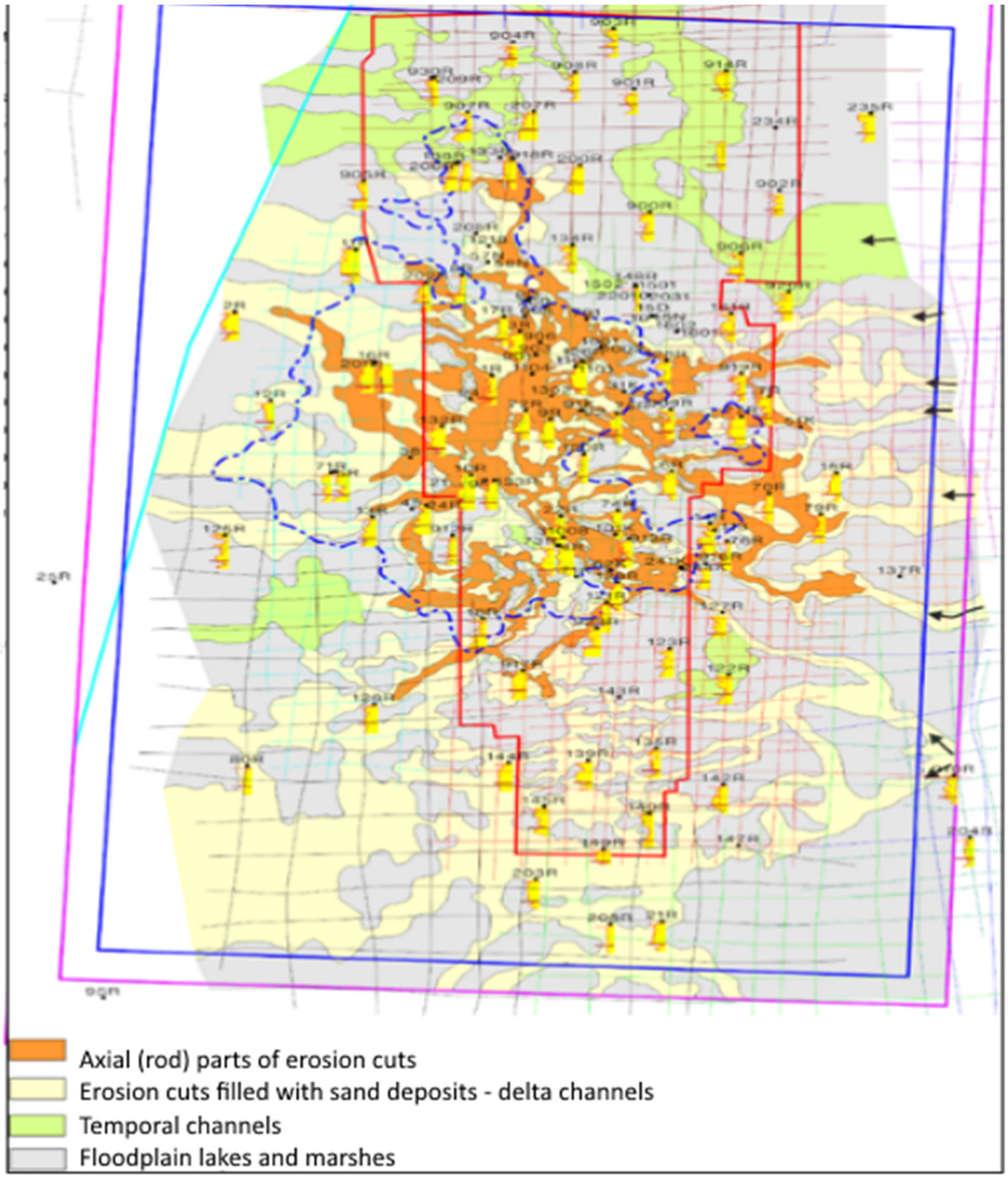


***Figure 11**. Map of sedimentation environments for the surface of the delta complex of the reservoir PC_1*

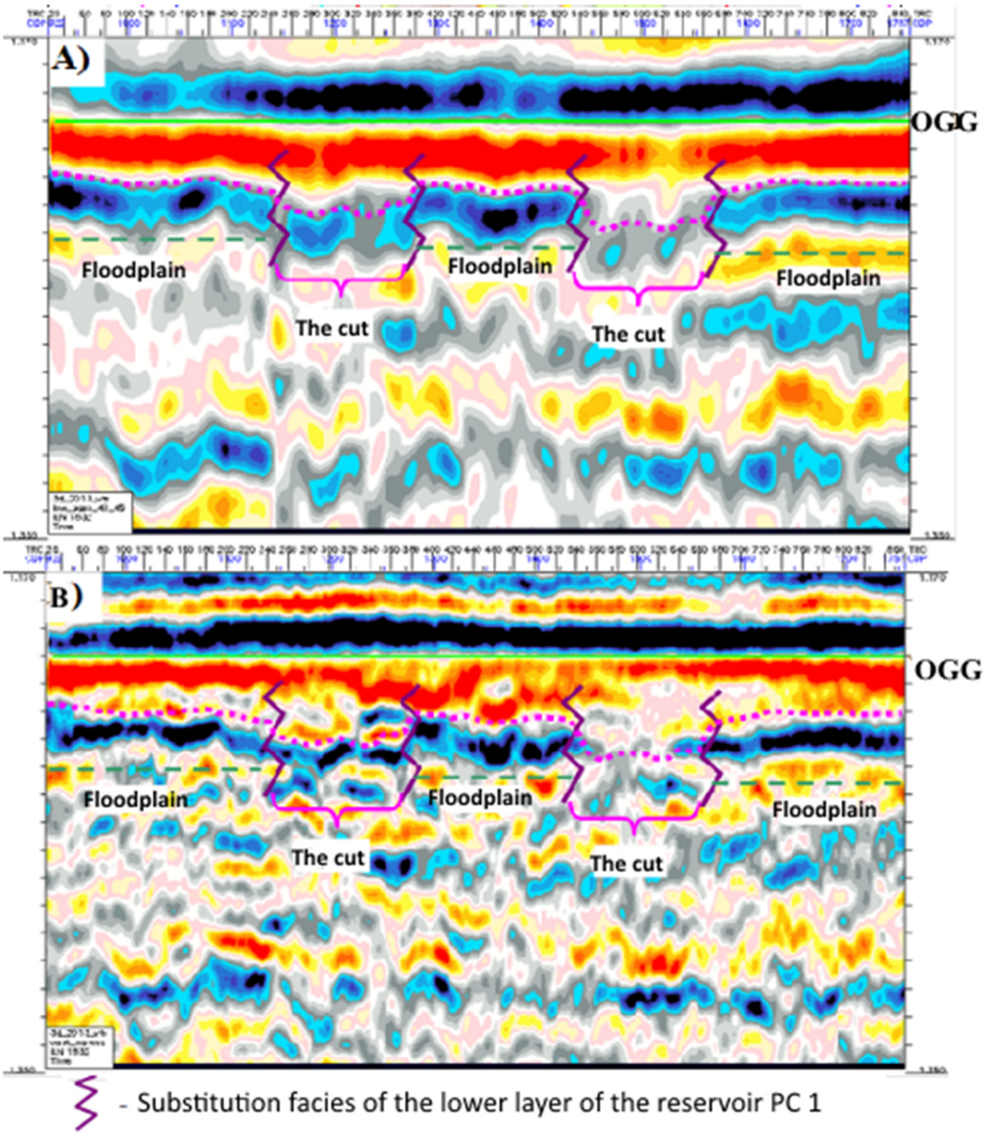


***Figure 12**. A fragment of a temporal section intersecting the regions of propagation of temporal ducts*