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# Carbonate formation of the Lower Carboniferous in central part of Volga–Ural basin

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**Carbonate rocks of the Lower Carboniferous (Tournaisian stage) of the central Volga–Ural basin (the eastern portion of the East European platform) are of practical scientific interest to geologists, particularly because they contain large reserves of oil. Although such layers have been studied, various questions pertaining to development of sedimentation schemes for the rocks have not been answered. We have attempted to resolve these by studying a wealth of drill core materials. The study involved structural and genetic analysis of rocks and facies reconstructions. The rocks are mainly represented by different types of shallow-water limestone. The thickness of coeval layers and their lithological structures changes from well to well within an oilfield, primarily due to the different environments of sedimentation during the Tournaisian**

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**stage. Therefore, to identify the characteristics of carbonate sedimentation, we have studied the sequences of different types of limestone and analysed their thickness. As a result, we have developed principle schemes of sedimentation for shallow-water carbonate rocks of the Tournaisian stage. This may help in the predictive search for reservoir rocks in the region of study.**

**Keywords:** Limestone, oil prospects, sedimentation, seabed topography, wave base level.

THE subject matter of this study includes shallow-water carbonate rocks from several oilfields in the central Volga–Ural anticline. Within the anticline, we specifically studied eastern portion of the Melekesskaya depression and western area of the South Tatar arch (Figure 1). At the Tournaisian stage of the Lower Carboniferous, these areas of the anticline evolved equally, but there are differences in the respective structures of the geological sections.

We have studied the rocks of the Tournaisian stage which contain large reserves of oil. The sedimentogenesis of these layers has been described earlier[1–4]. Considering similar types of sedimentary rocks worldwide, their sedimentogenesis has been described in the literature[5–8]. The Tournaisian stage of the Lower Carboniferous in the Volga–Ural region includes six horizons: Gumerovsky, Malevsky, Upinsky, Cherepetsky, Kizelovsky and Kosvinsky. Rocks of the Gumerovsky and Kosvinsky horizons are absent in the geological sequences of oilfields, whereas the other four horizons present regional oil saturation. Horizons are well allocated according to geophysical and lithological data. However, there is still no sedimentation scheme for carbonate rocks. Developing such a scheme is necessary, because drilling of structures without data on facies reconstruction in oilfields, often leads to negative results. Furthermore, sedimentation schemes can show the prospects of searching for oil reservoirs in similar strata outside the study area. Many of the ancient epicontinental basins in different parts of the world have similar structures. Thus, such schemes with respect to the reconstruction of sedimentary environments can actually be relevant to other oil-bearing provinces.

Drill core material from several oilfields, located on the eastern side of the Melekesskaya depression and the western slope of the South Tatar arch (in the eastern portion of the East Europe platform) has been studied. Core samples were selected from carbonate oil reservoirs of the Tournaisian stage. The cores are from more than 35 wells from different reservoirs, characterized by different industrial productivities and lithologies. We have studied core material from the Onbiyskoe, Demkinskoe, Letnee, Alekseevskoe and Tavelskoe oilfields. Core material was selected from different anticlinal structures and different parts of oil reservoirs, particularly from the central parts (domes) and flanks.

The study of core material started with the stratigraphic division and comparison with the geophysical interpretation data. The diameters of the core were 80 and 100 mm, and each core was cut along the axis for a more detailed and qualitative description of the rocks. Subsequently, we photographed the cores and selected representative samples for laboratory testing. Samples were taken at intervals of 20–40 cm. The samples reflected the type of rock, the sequence of strata and fluid saturation. We used X-ray diffraction, optical methods, SEM analysis and geochemical methods for the study. Additionally, we used data on petrophysical properties along with structural maps and data from geophysical studies.

The basic methods of the study involved analysis of facies, stadial, petrographic and mineralogical analysis of rock. Facies analysis predominates as the method of study. Its main purpose is to trace the lithological compositions of coeval rocks and the reconstruction of sedimentary environments. This method has been described in many publications, including those about carbonate rocks[6,7,9–12]. Stadial analysis is used to reconstruct the primary shape of the rock formation, wherein we consistently remove changes after sedimentation processes, i.e. the different stages of diagenetic changes, including

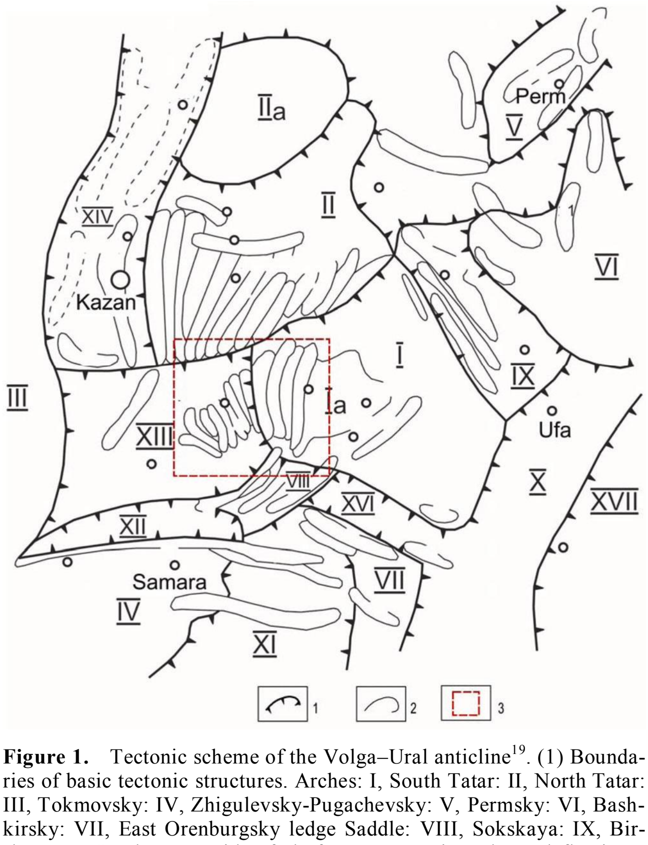


**Figure 1.** Tectonic scheme of the Volga–Ural anticline[19]. (1) Boundaries of basic tectonic structures. Arches: I, South Tatar: II, North Tatar: III, Tokmovsky: IV, Zhigulevsky-Pugachevsky: V, Permsky: VI, Bashkirsky: VII, East Orenburgsky ledge Saddle: VIII, Sokskaya: IX, Birskaya: X, Southeastern side of platform. Depressions, large deflections; XI, Buzulukskaya (northern part); XII, Stavropolskaya; XIII, Melekesskaya; XIV, Kazansky-Kirovsky; XV, Verhne-Kamskaya; XVI, Abdullinsky; XVII, Belskaya. (2) Boundaries of the second-order structures. (3) Locations of oil deposits researched in the study.

changes in oil reservoirs. Conclusions with regard to facies environments of sedimentation can only be drawn after the primary shape of the rock formation is reconstructed. The method of stadial analysis has been described by Yapaskurt[13,14] and Mahnach[15].

Our petrographic analysis dealt with the subtle structures and textures of rocks, such as mineral composition of rock-forming grains, their form and size, mineral composition and structure of cementing material, relationship between cementing material and rock-forming grains, types of organic remains and their quantity. Mineralogical analysis was used for qualitative and quantitative detection of mineral impurities in rocks (fine particulates and clay minerals), which cannot be detected with traditional petrographic analysis.

Earlier studies and our data on the Volga–Ural region have made it possible to identify several types of limestone in the Lower Carboniferous (Tournaisian stage), which were formed in tropical shallow sea water environments. We selected two structural types of limestone, according to the classification by Dunham[16] and Embry and Klovan[17]: peloidal grainstone and algal wackestone. All the types encountered are well defined in sections and often form mixed associations.

Peloidal grainstone is widespread in all horizons of the Tournaisian stage, but it is dominant in the Upinsky and Kizelovsky horizons. It has uniform oil saturation in geological sections and, subsequent to oil extraction, it has a light-grey colour and uniform rock texture (Figure 2).

Rocks often contain shallow-water organic remains, including fragments of crinoids, brachiopods and single corals. Peloidal grainstone, as seen under the microscope, consists of round and oval peloids (granular organic remains). Peloids are comprised of micrite and are cemented by sparite (Figure 3).

Prior to the formation of peloids, at an early stage of the diagenesis, formative components of limestone had undergone granulation. In our opinion, most of them were benthic foraminifera that have undergone granulation. Moreover, peloids primarily are foraminiferous. Further, under the conditions of late and deep diagenesis, a considerable part of the primary micrite material was leached and a portion was recrystallized to sparite. Sometimes, we can detect the primary micrite in parts that have had less exposure to the process of dissolution and recrystallization.

Algal wackestone occurs as irregular layers in the Cherepetskaya and Kizelovsky horizons of Tournaisian

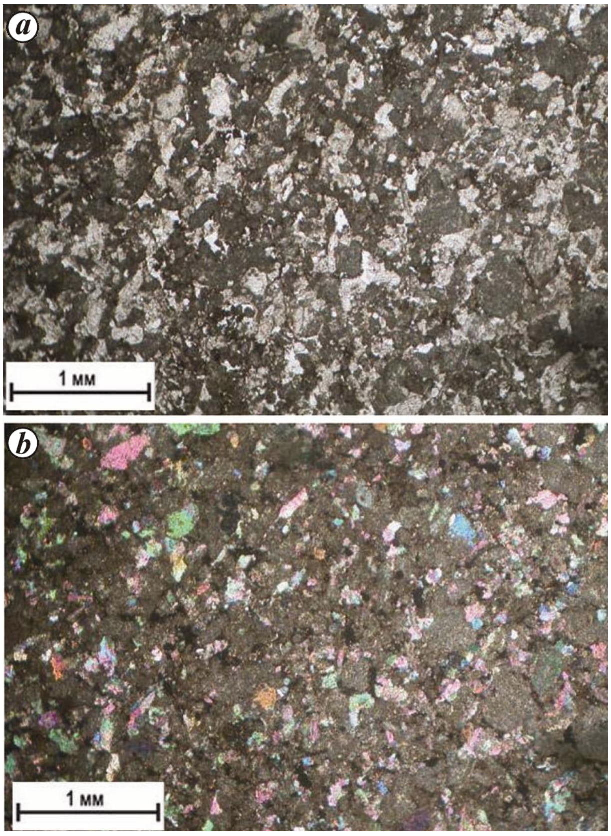


**Figure 3.** Photomicrographs of peloidal grainstone: ***a***, under polarized light; ***b***, under crossed Nicols.


**Figure 2.** Peloidal grainstone: ***a***, oil-saturated; ***b***, after oil extraction.

**Figure 4.** Algal wackestone.

stage. It is grey in colour, has a wavy, lenticular bedding structure caused by carbonaceous-clay interlayering and detrital biogenic texture (Figure 4).

In algal wackestone, the rock-forming components are algal detritus up to 1 mm, which is cemented by basal micrite. Algal detritus mainly occurs in the bed (Figure 5). Occasionally there are organic shallow-water organic remains, such as fragments of brachiopods, crinoids as well as single corals. Sometimes, authigenic pyrite occurs. In Russian journals, such rock material is referred to as organogenic detrital limestone[18]. Insoluble residue of algal wackestone is clastic silt material and clay. During diagenesis, a significant portion of the hollow algae has been filled with large grains of calcite. Generally, little change has occurred after diagenesis of the limestone.

Tournaisian-stage geological sections differ in structure in the Volga–Ural region and even within a single oilfield, where the distance between geological sections ranges up to several kilometres. Such a difference is particularly characteristic of the Kizelovsky horizon. Moreover, the thickness, sequences of strata and the content of different types of limestone can vary within a horizon. These facts allow us to distinguish two types of Tournaisian sections (type A and type B). The main difference between the sections is illustrated by the structural differences that exist between the Kizelovsky horizon and the Cherepetskaya horizon (Figure 6). The structure of the Upinsky horizon is consistent.

Type A sections are prevalent throughout the Volga–Ural region. The thickness of the Upper Tournaisian sequences is 32–40 m; however, in the Kizelovsky horizon it is 14–16 m and in the Cherepetskaya horizon it is 18–24 m. We consider only the Cherepetskaya and Kizelovsky horizons, because they represent the greatest difference between the type A and type B sections. These horizons are comprised of peloidal grainstone, algal wackestone and mixed types. The Cherepetskaya horizon is comprised of algal wackestone with thinly interbedded peloidal grainstone. Peloidal grainstone increases towards the top of the horizon. However, peloidal grainstone, when taken collectively, does not exceed 10–15%. The Kizelovsky horizon has a more complicated structure due to the alternation of peloidal grainstone and algal wackestone. Peloidal grainstone forms two layers in the lower and upper sections, with a thickness of 2–3 m and a 30–40% share of the horizon. The compilation of data allowed us to construct the geological section, which is classified as type A (Figure 7).

The type B geological section is unevenly distributed in the region. The thickness of the upper Tournaisian sequences is 22–27 m. In the Kizelovsky horizon it is 8–11 m, whereas in the Cherepetskaya horizon it is 14–16 m. The data on thickness indicate the differences among lithological sections. The Cherepetskaya horizon is comprised of algal wackestone and peloidal grainstone, in which the share of peloidal grainstone is 1–5%. The

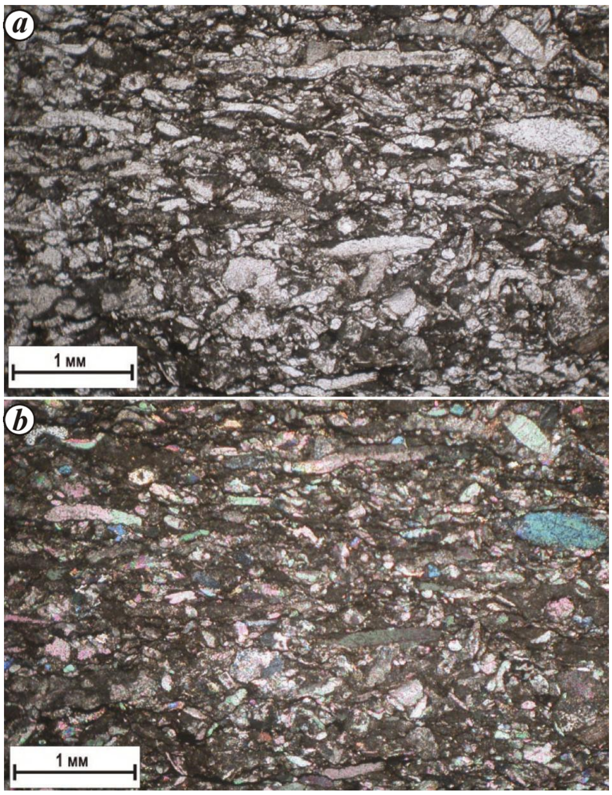


**Figure 5.** Thin sections of algal wackestone: ***a***, under polarized light; ***b***, under crossed Nicols.

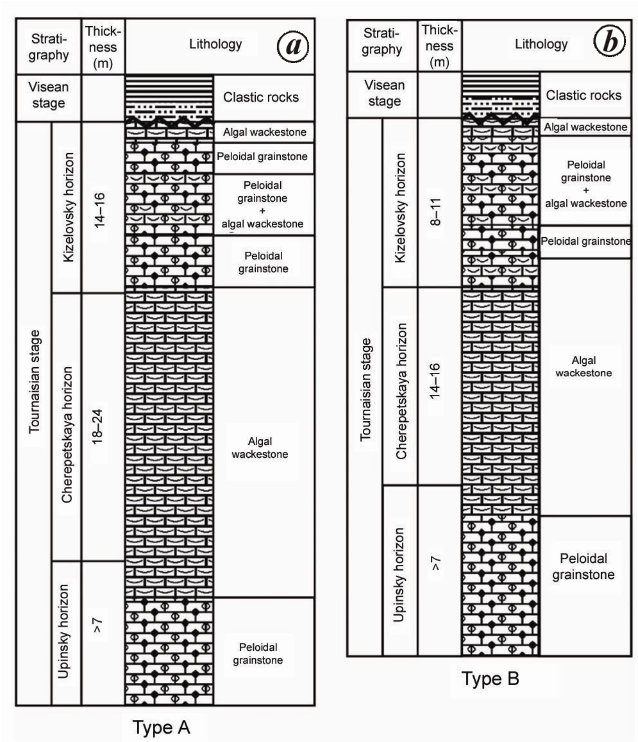


**Figure 6.** Types of Tournaisian geological sections in the Volga–Ural region.

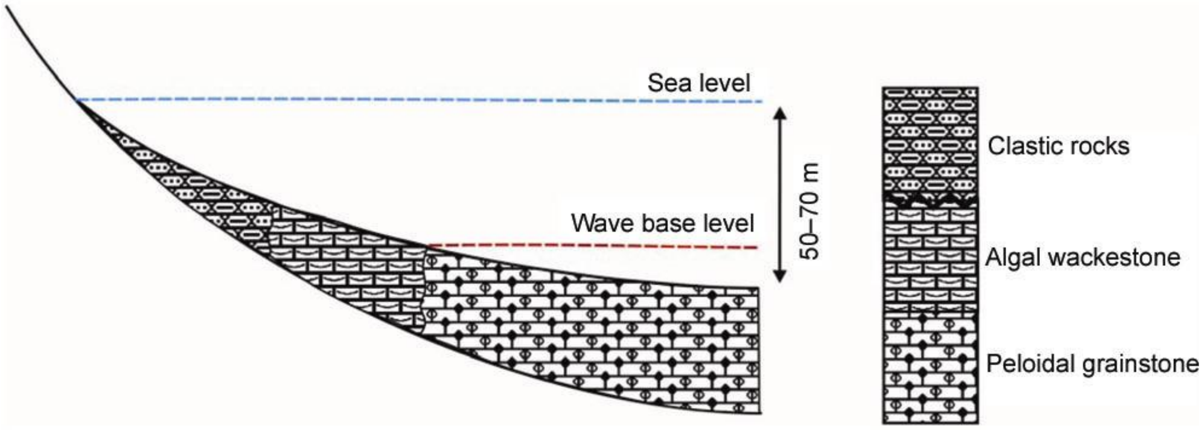


**Figure 7.** General scheme of sedimentation: Tournaisian stage, central Volga–Ural region.

Kizelovsky horizon differs from the same horizon of type A section. It is thinner in this horizon; the peloidal grainstone is also thinner and contributes to a lower share. Peloidal grainstone forms layers 0.5–1 m thick, and their share in the horizon is 10–15%. Algal wackestone and mixed limestone (peloidal grainstone-algal wackestone) predominate. The compilation of data allowed us to construct the geological section, which is classified as type B (Figure 7).

Different parts of the Volga–Ural region developed in different directions[19]. Moreover, the topography of the seabed was a strong factor in sedimentation, which was inherited from the Devonian period, when there were widespread reef complexes. The literature and other data allow us to create a sedimentation scheme. The depth of sedimentation was 10–70 m (ref. 2). It was a shallow marine shelf of the epicontinental carbonate platform. The general sedimentary scheme in the central Volga–Ural region is shown in Figure 7. The sections show sequentially occurring limestone from relatively great depths up to shallow-water limestone, where peloidal grainstone is successively supplanted by algal wackestone and clastic rock. However, the scheme shows only the general regularities of sedimentation in the Tournaisian stage, and consequently various facts are not considered:

(1) Two types of geological sections exist (type A and type B). (2) The thickness of the Kizelovsky and Cherepetskaya horizons differs in the A- and B-type sections. (3) The share of peloidal grainstone differs between the A- and B-type sections.

The scheme also omits certain factors in the control of carbonate sedimentation, such as wave base factor and seabed morphology. These factors have been considered important with respect to sedimentation and description[5,7,10,20–26]. We have shown the impact of these factors on sedimentation schemes for the A and B types of the Tournaisian sections.

The wave base, when considered as a factor, creates specific erosion textures in the rocks. Moreover, it has importance in the reconstruction of sedimentary environments, because the wave base level controls the positions of rock fragments (rock-forming components). The analysis of limestone shows that algal wackestone has formed at or above the base level. This is evidenced by the high proportion of algal debris, often with a horizontal bedding and a wavy, lenticular texture of inwash and rewash. In this limestone detrital material is often observed in the form of large fauna debris, which generally consists of brachiopods and crinoids. Additionally, the algal wackestone contains terrigenous material in the form of quartz, feldspar and clay minerals in an order that exceeds the proportion of terrigenous material in peloid grainstone. Transitional types of limestone between the peloid grainstone and algal wackestone no longer bear, in any practical sense, traces of waves or of the rewash of accumulated sediments. Peloidal grainstone has a massive, homogeneous texture, but lacks the properties of wave influence. We believe the peloidal grainstone has formed in a relatively quiet hydrodynamic regime, below the wave base. This is indicated by relic primary micrite, which serves as a cementing material for peloids. Additionally, there is no texture that points directly to high-energy depositional conditions. Thus there is no bedding trace of rewash and inwash. The stone is normally distributed throughout the layer and has an exceptionally uniform texture.

Mixed limestone was formed closer to the line of the wave base. The analysis of data allowed us to develop the sedimentary scheme for the type-A and type-B sections (Figure 8 *a* and *b*).

The scheme thus developed here shows the relative depths of sedimentation for different types of carbonates and changes in the depth of the epicontinental sedimentary basin during the Tournaisian stage. The curves of depth indicate the formation of different types of carbonate rocks, and also show the changes in depth in different parts of the Volga–Ural basin from the Tournaisian stage. The reconstruction shows that the sedimentation of

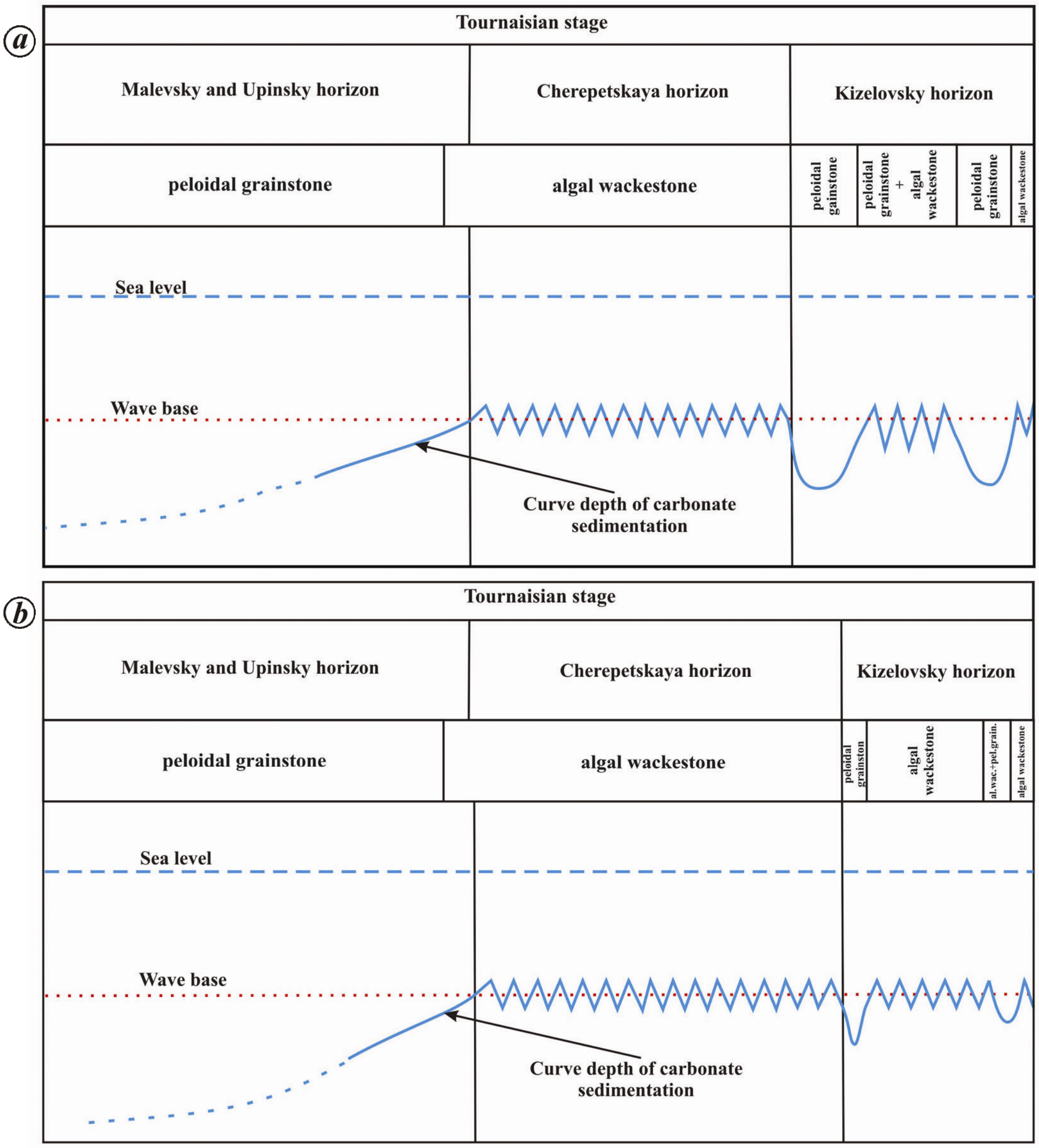


**Figure 8.** Reconstruction of carbonate sedimentation depth: ***a***, type A; ***b***, type B.

carbonates occurred in the basin with dissected seabed. The sedimentation of type-A sections occurred at relatively greater depths compared to type-B sections. The area of the Melekesskaya depression in the Tournaisian stage was shallow compared to the west side of the South Tatar arch. However, we believe the difference in depth is not a significant consideration, because the paragenesis of rocks occurred repeatedly, albeit in different proportions.

In conclusion, geological sections differ not only within a region but also within a single oilfield. Therefore, we must provide a detailed analysis of every geological section from every well. This is important in the study of factors that predominate during sedimentation and consequently the search for oil reservoirs in a given area. The main factors that differentiate geological sections are seabed morphology and depth, including the position of the wave base. Oil-saturated limestone is peloidal grainstone, formed below the line of the wave base. Geological sections that have formed in relatively deep depositional environments offer relatively better prospects for oil than shallow sections.

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