Study of the Paleozoic Base of the Terek-Caspian Trough Based on the Complex of Geological and Geophysical Data

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***Abstract*—The article presents the primary results of paleotectonic studies that were conducted in order to study the deep structure of the Paleozoic basement, to reveal the patterns of development of the faulty-block tectonics of the Terek-Caspian trough, kinematic features of tectonic movements, and their contribution to the formation of the modern structural plan of the region. During the course of the work, the analysis of the capacities and facies of all carbon units was carried out on the basis of the summary of the available drilling data, seismic and other geophysical materials. As a result of the studies based on the analysis of geological, geomorphological and individual geophysical methods, the structural-formational profiles, the sedimentation rate graphs and the thickness map of the Cretaceous sediments of the sedimentary cover were made, and the elements of the deep structure, spatial position and activity time of separate interblock zones - faults were revealed. The article presents the data concerning the history of the formation and the degree of activity of separate faults on the territory of the Terek - Caspian trough. During the pre-Jurassic period, the investigated territory had already possessed a whole system of blocks bounded by faults, and the subsequent significant changes in the structure of the Upper Cretaceous structural plan were determined as a result of the intense manifestation of ascending movements. The formation of structural - tectonic elements in the areas of the intensification of the vertical movements of the blocks of the basement along the faults during the general rise of the territory led to the bending of the Upper Cretaceous bedrocks. At the same time, each unit developed independently. It is reflected in the composition of rocks and their thickness. The movements of the Mesozoic blocks of rocks in the early formed fractures caused a further complication of the structural-tectonic plan of the Upper Cretaceous sediments, which was reflected in an increase in the slope of the wings, their fragmentation by systems of disturbances, and the increase in tectonic fracturing. It is necessary to note that the intensity of the tectonic activity of separate faults at various stages is differentiated, in some cases, at certain stages of time there was a change in the sign of movements. In general, the region was subject to long-term general meridional compression processes with the formation of linear structures as well as processes associated with the reorientation of block compression and right-shift processes. It is proved by the nature of the link junction of folded structures within the investigated region.**

Keywords—sediments; sediment accumulation rate; fracture; block-system; Terek-Caspian trough

I. INTRODUCTION

Thick series of Precambrian, Paleozoic, Mesozoic, and Cenozoic ages are included in the geological structure of the trough. The fault-block foundation structure played a decisive role in the formation of the structure of the sedimentary cover. The peculiarity of the structure of the sedimentary cover of investigated territory is presented by the clearly pronounced disharmony of folding of various structural and formational stages in the sedimentary cover, which is a reflection of the change in the mode of sedimentation.

The fault-block foundation structure has played a decisive role in the formation of the structure of the sedimentary cover. The peculiarity of the structure of sedimentary deposits is the pronounced disharmony of folding of various structural and formational stages.

The study of the formation mechanisms of faulty-block structures will allow identifying the factors that influence the structure formation of the trough and especially the folding in the Terek and Sunzhensky anticlinal zones.

The purpose of this work is to study the deep structure and fault tectonics by geological and geophysical methods. The tasks of the research include the study of the deep structure of the sedimentary cover, sedimentation conditions, and the determination of the location and activation time of individual faults as well as the conditions and factors determining the formation conditions of individual local tectonic structures at great depths.

II. Research Methods

The method of analyzing the distribution of thickness is the most informative among those used in paleotectonic research. This method allows obtaining not only qualitative, but also a quantitative assessment of tectonic movements (mainly their vertical components). As a rule the oscillations of bottom are controlled by faults of different rank and are detected by sedimentation characteristics. They present discontinuous displacements inside and on the periphery of sedimentation basins. They are active during sedimentation in these basins.

The analysis of changes in thickness is based on two initial positions: firstly, it is assumed that sediments in the initial bedding form a horizontal surface; secondly, the thickness of the sediments deposited over a certain period of time is approximately equal to the subsidence amplitude during this time. According to the relative fluctuations of thickness it is possible to determine the manifestation of tectonic movements of a positive or negative characteristic in a particular area of the study.

The assessment of the rate of compensated sedimentation allows determining and estimating the rate of tectonic movements. The comparison of tectonic modes of sedimentation of various structural zones for a certain segment of geological time emphasizes the faulty-block nature of the foundation structure and makes it possible to set the time of individual periods of tectonic activation of faults. When comparing the rates of tectonic movements, their absolute values and contrasts are estimated, i.e. the difference in intensity of vertical tectonic movements of adjacent blocks.

It is necessary to note that paleotectonic analysis was tested in the greater extent for areas of the platform type and is relatively rarely used for the analysis of fault tectonics in folded areas. Methodological grounds of estimates and comparisons of paleotectonic analysis are reflected in numerous published works [3, 9, 12].

III. Results and Discussion

On the territory of the Terek-Caspian trough, the beginning of the formation of a sedimentary cover refers to the Early Jurassic stage of development – the beginning of the Pliensbachian century.

The modern structural plan for the top of the Jurassic-Lower Cretaceous sediments is a reflection of the continuous and interrupted development of tectonic movements [2, 6, 10, 14]. Deep faults determined the development of the region as a whole. Their periodic activations are observed throughout the entire history of geological development, which made it possible to identify several faults and separate blocks within the investigated area.

However, the estimation of the rates of vertical movements, due to the lack of the corresponding factual material, was carried out from the horizons not earlier than the late Cretaceous. In general, the actual material on the normal thickness of the section includes data from more than 600 deep wells and in while determining the absolute time, the “Geochronological scale of the Phanerozoic ...” [1] was used.

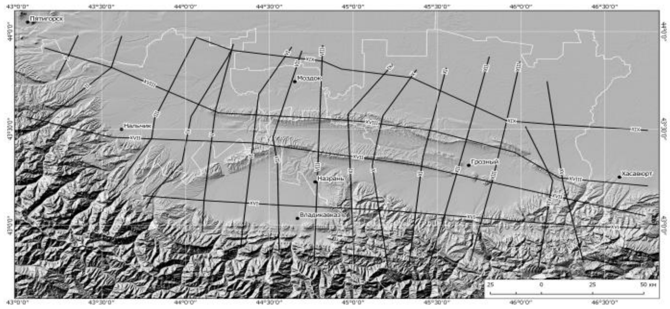

Fig. 1. The schematic illustration of structural and formational profiles.

In general, the Upper Cretaceous sediments are characterized by a rather complete consistency throughout the investigated area, although in some areas there were short breaks in sedimentation, expressed in the discordant bedding of Turonian and Cenomanian, Maastricht and Campanian, Danish age and overlying Paleocene. By this time, the manifestation of the Sub-Hercynian and the beginning of the Laramide phases of tectonic activity. The Late Cretaceous period can be divided into several stages by the nature of the tectonic activity.

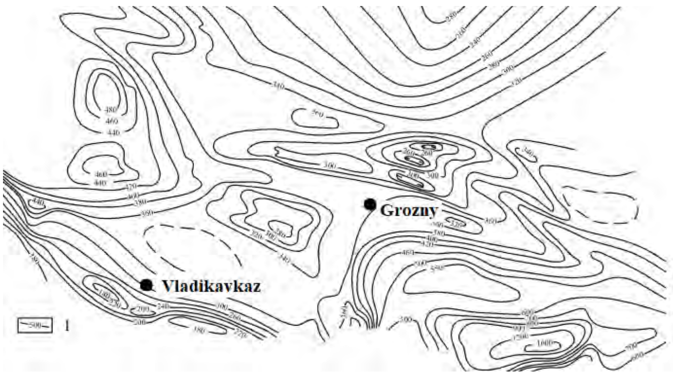

Fig. 2. The thickness map of Cretaceous sediments of the Terek – Caspian trough.

The first stage covers the Cenomanian-Santonian time intervals characterized by a slow sedimentation rate over the entire territory with values from 2 to 8 m / million years, at this stage there is a continuing activation of the Chernogorsky and Terek sub-latitudinal faults, the Ardon fault orthogonal to them of, separating blocks with different accumulation rates. The distance between the faults is 25-35 km. In the East, the activation of the Argun fault is noticeable (strike 5 ° -10 °).

The second stage covers the Campanian and Maastrichian centuries and is indicative of the increase in sedimentation rates of up to 15–20 m / million years. The exception is the area between the Sunzha-Assa-Fortanga interfluve, where an increase in sedimentation rate occurred only during the Maastricht time. This area is a single block with a size of 30x35 km of the North-West strike, bounded by the Kazbek and Dattykh-Akhlovsky faults.

At the Kampan-Maastricht stage of development of the territory, the highest sedimentation rates in the monocline zone of the northern slope of the Greater Caucasus were characterized by the Baksan region, where the rates were 30–35 m / million years. In the Roshnya-Martan-Argun river basins, the rates increased up to 40-45 m / million years, and in the Bass-Khulhullau-Argun-Elistanzhi river basin increased up to 80 m / million years. Here, the continuing activation of the zone of junction of the Dattykh-Akhlovsky and Argunsky faults, dividing blocks with different rates of immersion manifested itself.

In general, the Late Cretaceous sedimentation basin is characterized by a slight slope to the South-East and by a steady relative uplift of the Korinsky, Fiagdonsky, Gekhinsky noses. In the Terek-Sunzhensky area, the Karabulak-Achaluksky, Malgobek-Voznesensky, Khayan-Kortsky, Mineral blocks were rising, and the Ossetian and Chechen blocks were intensively subsiding. The last block experienced the most significant subsidence, especially near the Chernogorsky fault. Block sizes vary considerably from 5 ÷ 8 km to 20 ÷ 30 km; the blocks limited by faults of rank 1 on the scale of research are the most distinguished.

Thus, the analysis of the thickness and sedimentation rates of the Upper Cretaceous sediments indicates that a sufficiently differentiated geotectonic plan had already taken shape at the end of this epoch.

Regional disjunctive structures of crust are identified by many researchers as deep faults and, unlike near-surface faults, deep faults are characterized by large length, considerable depth of development, long duration of development and, accordingly, they divide the crust into blocks differing from each other in structure, mode and developmental history.

The last feature is of great importance in areas with significant thickness of sedimentary formations. The differences in the mode and history of development of each area can be expressed in many features of their structure, but a reliable criterion for their existence is the section of sediments, and especially the different thickness of rocks [3, 2].

This is explained by the fact that the thicknesses of sedimentary formations mainly determine the amount of subsidence of the sedimentation area in a given interval of geological time. In addition, a large variety of sediment thickness, even at a relatively short distance (sometimes a sharp increase or decrease) makes it possible to evaluate the different subsiding intensity of closely located areas.

Apparently, these areas present independent blocks with their mode of oscillatory movements (subsiding). Such blocks could be formed if they were separated from each other by natural boundaries with favorable conditions for free vertical movement, with the subsequent formation of each of them into separate tectonic zones [7, 13]. In other words, the blocks could give independent development to faults that limit them. It is the above-mentioned considerations that underlie the principle of isolating blocks of different age, mode, and size of the occupied area and the faults separating them.

For the structural-formational constructions, three zones of the latitudinal direction were chosen: Benoysky (Southern) direction, Sunzhensky (Central) and Bragunsky (Northern) directions. The most complete data on sediment thickness is available in the South direction, since here it is possible to use the thickness of rocks along closely located natural rock yield. In other areas (Sunzhensky and Bragunsky) there are insufficiently complete data for all the wells.

For a uniform spread over the area of “observation points”, the thickness maps were created. According to the maps the thickness values of particular stratigraphic subdivisions were selected for “missing” elements in the construction of “points”. Such a selection of “points” was also dictated by the fact that the authors considered the formation of faults and the development history of the blocks during the entire Alpine geotectonic stage, i.e. from the Early Jurassic to the Quaternary period, and this stratigraphic interval is not revealed by all the wells.

In the Early and Middle Jurassic period, the Western part of the zone, approximately 50 km from the boundary of the investigated area, was an area of denudation and corrosion (land), while the Eastern part in the early Jurassic period accumulated a thick layer of sediments.

Thus, this zone can be taken outside the boundary between the area of rising and the area of subsidence (land and sea). Moreover, near this boundary the sea zone descends to 800 m, with a rate of 0.024 mm / year. These data indicate the presence of a major fault along the boundary of two regions of different tectonic development, or large blocks. The surface of the seabed, where sediments accumulated, was extremely uneven. Coastal zones are elevated, in relation to the intensively descending Central part. Such a relief form of the bottom of the basin is caused by different rates of their subsidence.

Thus, the rate of subsidence of the Central part of the trough varies from 0.044 mm / year to 0.059 mm / year, while on the yield its “trough” rate does not exceed 0.023 mm / year in the West and 0.009 mm / year in the East. Such sharp (more than double) changes in the rate of subsidence various zones can be explained by their independent development. The faults separating the above mentioned blocks from each other were previously named as Ursdonsky and Argunsky [6, 5].

Late Jurassic period is characterized by increased tectonic activity in almost the entire investigated area. Even the borderlands of the investigated area are covered by high subsidence rate. So, in the West, the area of the rate of subsidence increases from 0.032 mm / year to 0.074 mm / year, and in the Eastern part – from 0.015 mm / year to 0.072 mm / year. However, the Central part remains the most active part of the whole area, where the subsidence rate reaches in some areas up to 0.099 mm / year. Such highly active tectonic movements, moreover, differentiated by area, led to a clear formation of such faults, which appeared in the early and middle Jurassic period, but did not show such significant activity that they could influence the accumulation conditions and the value of sediment thickness.

In the early Cretaceous, the oscillatory movements got weaker than in the previous period. The subsidence rate of the selected blocks did not exceed: 0.030-0.040 mm / year in Neocomian period and rarely reached 0.064 mm / year, in the Apto-Albian time in the South direction in some areas it increased to 0.050 mm / year, and in Northern areas the subsidence rate of the blocks remained at the same level. Against the general background of weak subsidence of the blocks, the zones with more active movements were found - these were the interfluves of the Urukh-Ursdon and Sunzha-Fortanga rivers. Thus, during the Jurassic and Early Cretaceous periods, a significant number of faults developed on the area, limiting the blocks of crust.

From the total land to the East and along the Northern directions (as well as along the Southern) the sea basin developed with the accumulation of thick sedimentary layers in the Meso-Cenozoic period. The analysis of the sedimentary sequence of the Meso-Cenozoic, especially the value of the thickness of the sediments, on the basis of which the subsidence rates of the blocks were determined, showed that many Southern faults spread to the North, forming a single network of meridional faults.

In the Sunzhensky direction in the field of sedimentation, there were three different zones with different power values and different composition of rocks. In terms of their tectonic activity, these three zones were inferior to the Southern ones, but still had a high subsidence rate: 0.021–0.028 mm / year in the Western part; 0.020-0.051 mm / year in the Central and 0.015-0.021 mm / year in the Eastern part.

The borders were the areas (from the West to the East, respectively): the basin of the Baksan River, to the Eastern end of the Sunzhensky anticline and further to the Dagestan structural raising of basement.

A similar situation was observed in the North direction. There were also three zones with independent development: Western, Central and Eastern.

In addition, in the Central (Sunzhensky) direction, two new faults were distinguished (Karabulaksky and Sernovodsky), which were not fixed in a Southern direction. At the same time towards the Northern directions, some Southern faults were not active. In view of this, if there were 26 faults in the Southern direction, only 21 faults were fixed in the Central direction, and 19 faults in the Northern direction.

The above mentioned material indicates the presence of a series of meridional faults on the investigated area, dissecting the area into blocks. In other words, the sedimentation basin, beginning from the Early Jurassic period, was divided into peculiar sedimentation baths of meridional strike. In further periods, each bath developed independently, with the accumulation of sediments of a certain thickness and composition in them.

Several conclusions:

1. As early as in the pre-Jurassic period, the investigated area already had a block structure, since the active oscillatory movements that had appeared here already in the early and middle Jurassic outlined the whole system of blocks limited by faults.

2. In the early and middle Jurassic period, the investigated area, first of all, was characterized by denudation area (land), located beyond the Western borders of the area, and a sedimentation area (seabed deflection), covering the whole territory. The three directions chosen by us were located from the South to the North along the strike of the deflection.

3. The Southern direction was subject to more intensive subsidence due to its proximity to the tectonically intense axial zone of the Caucasian anticlinorium.

4. The first faults that originated in the South probably developed intensively in the Late Jurassic period and spread to the North, forming a system of latitudinal blocks — baths, 5 to 15–20 km. Further, underwater blocks developed independently, which was reflected in the composition of rocks and their thickness.

5. In the Cretaceous period and the Paleocene-Eocene period, the rate of development, both of the entire area as a whole and of individual blocks decreased to some extent.

6. In the Mesozoic period, the Central and partly Western zones of the area were subject to relatively rapid subsidence. The Northern and Eastern parts of the area were characterized by weak subsidence rates, i.e. marginal parts of the sea deflection were raised. Apparently, the Bragunsky direction and the basin of the Aksay River were located near a large, time-resistant rising (land), which supplied abundant terrigenous material into the sedimentary basin at the end of the Paleogene and Neogene periods.

Tectonic style. Significant changes in the structure of the Upper Cretaceous structural plan were determined as a result of the intense manifestation of upward movements. The formation of structural - tectonic elements in the areas of the intensification of the vertical movements of the basement blocks along the faults with a general rise of the territory led to the bending of competent Upper Cretaceous rocks [5, 11, 15].

In the areas with a less degree of activation of block movements, the last one led only to movements of the Upper Cretaceous-Upper Jurassic blocks without affecting the Middle Miocene rocks due to the high ductile properties of the Maikop-Lower-Chokrarsky series of sediments, which plays the role of an amortization layer.

After the Pre-Akchagylsky stage was completed, the dynamic balance was established during the Pliocene and Anthropogenic periods: the denudation of structures brought to the surface and the accumulation of the largest volume of acchagyl-Apsheronian deposits in the distant submerged areas of the separated positive structural zones (by the Miocene complex).

The next stage in the activation of the ascending movements of the basement blocks appeared in the late Quaternary time. This is evidenced by the completion in the Western part of the Eldarov and Goryacheistochnensky folds - the anticlines of the Quaternary sediments in the sub-thrust parts of these folds, i.e., covered by more ancient Chokrak sediments. The repeated movements of the Mesozoic blocks of rocks in the early formed gaps caused a further complication of the structural-tectonic plan of the Upper Cretaceous sediments, reflected in the increase of the wings over steepening, their fragmentation by systems of disturbances, and the increase in tectonic fracturing. The maximum amplitudes of the Late Quaternary block movements were observed within the Terek, Region, and Chernogorsky areas, in the Western part of the Mozdok fault. In the zones of such intensive crushing, the most severe changes underwent sediments from Middle Miocene to anthropogenic period.

It is necessary to note that the nature of movements of faults is most often represented as a right shift. The intensity of the tectonic activity of individual faults at various stages is differentiated, in some cases, at certain stages of time, the characteristic of movements changed.

IV. CONCLUSION

The formation and transformation of the structural plan (starting from the Jurassic period) took place in the process of a long stage-by-stage consediment process. The decisive role in the formation of local risings (structures) in the investigated area was played by the following stages of activation of the ascending differentiated block movements of the basement: the Paleocene-Eoecene; the Oligocene-Early Miocene; the Pre-Akchagylsky (Late Miocene) and the Late Quaternary periods.

In general, the region was subject to long-term general meridional compression processes with the formation of linear structures as well as the process associated with the reorientation of block compression and right-shift processes. This was evidenced by the nature of the fold junction of folded structures within the investigated region.

According to the nature of the formation and development of the Upper Cretaceous structural plan and depending on the degree of manifestation of block movements, the faults can be divided into:

- The faults of continuous unidirectional development (Chernogorsky, Terek and others);

- The faults of continuous multidirectional development (Gudermes, Argun, etc.);

- The faults of interrupted action (which lost their structure-forming value at one of the subsequent stages of the activation of basement movements).

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