A new scheme of tectonic zoning of the lithosphere upper part of the Pre-Caspian depression

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SUMMARY

The article presents a preliminary scheme of tectonic zoning of the lithosphere upper part of the Pre-Caspian depression eastern part, compiled on the basis of seismic-density models for 6 deep seismic sounding profiles. Models are built using deep seismic geo-mapping technology. The basis is a fault-block, layered, hierarchical model of the structure of the lithosphere upper part as the most appropriate geological environment. The model consists of seismogeological floors with sustained values of speed and density. Two surfaces between them are supporting. The boundary of the crystalline crust is represented by the surface of the Lower Archean granite-gneiss foundation. The second reference boundary is the surface of the main seismological section M between the lower crust and the upper mantle. It is shown that ancient platforms and their megablocks in the eastern part of the Pre-Caspian depression are separated by deep submeridional and sub-latitudinal border zones. It is concluded that the tectonic factor is crucial in the formation and subsequent dynamic transformations of the Pre-Caspian depression.
Introduction

Existing tectonic maps of the Pre-Caspian depression (PCD) are based on seismic and geological information about the sedimentary layer, the relief of the consolidated basement, and the surface of the seismological boundary M. The Pre-Caspian depression has a complex structure in tectonic terms (Druzhinin et al., 2019a, 2019b). Attempts to generalize information on a numerous profiles of deep seismic sounding (DSS) have been made repeatedly. However, the use of heterogeneous, non-interconnected information did not give a real idea of the formation nature of PCD (Aplonov, 1995; Artyushkov, Egorkin, 2005, Leonov et al., 2010, Panina, Zaitsev, 2016).

According to the technology developed at the Institute of Geophysics UB RAS, 2D seismic-density models were compiled for individual sections of the Urals region for almost all available DSS profiles and tectonic zoning schemes were constructed (Druzhinin et al., 2014, Druzhinin et al., 2017). In constructing of the model, a deep geo-mapping method of the environmental geological area was used, according to which the main structural elements of the continental crust are seismic-geological floors (SGF), which differ in structural and tectonic features, physical parameters and geodynamics (Druzhinin et al., 2014). The floors are separated by section surfaces, three of which are reference. The first surface $K^*_{01}$ corresponds to the surface of the consolidated basement or the roof of the lower megacomplex of the first SGF, the second to the Lower Archean granite-gneiss foundation $K_{01}$, the third to the seismic-geological discontinuity $M$ between the lower crust and the upper mantle. In addition to the reference ones, surfaces are distinguished in the crystalline crust, possibly the $K_2$ proto-crust and the $K-M$ core – mantle transition complex. Within each SGF, blocks differing in structural-tectonic features and physical parameters are distinguished. The boundaries of the blocks can be traced in the SGFs adjacent in depth, some of which extend to the entire thickness of the crust and upper mantle.

This article presents the results of work on the eastern part of the Pre-Caspian depression, performed by the method of deep geo-mapping. This structure is part of the East European Platform (EEP) and the Urals Folded System (UFS) (Leonov et al., 2010).

Research content

The application of the developed technology of seismic-geo-density modeling of upper part of the lithosphere (UPL) to a depth of 80 km made it possible to uniformly compose 2D seismic-geo-density models for 6 DSS profiles along the eastern part of the PCD (Fig. 2), with a total length of over 4000 km (V. S. Druzhinin et al., 2019c).

The complexes of the first SGF are represented by geosynclinal, folded, sub-platform structures in a wide age range from the Lower Proterozoic at the EEP to the modern ones, reflecting the stages of geological transformations. The lower megacomplex of the first SGF is characterized by significant variability in the composition and physical parameters of rocks of $PR$ age. Its thickness varies from 0–2 km in the ancient uplifts to 7–10 km in the depressions of the EEP.

The second reference surface of the seismic-density model is the $M$ boundary, considered as a transition from rocks of the lower crust to mantle complexes. It is assumed that in PCD this transition occurs through a layer of complex structure with a thickness of 10-12 km, with the presence of horizontal and subvertical inhomogeneities with varying velocity parameters in the range of 7.0–8.0 km/s. In geosynclinal folded formations, such as UFS, transition zones of increased thickness up to 15–25 km are observed, depending on the scale of transformations. The upper boundary of the transition layer in the sections along the DSS profiles in the PKD is at a depth of 35–37 km and is marked as $M^*$.

The presence of a proto-crust is proposed in the crystalline crust below the surface of $K_{01}$, designated as $K_2$. In standard seismic sections, this sign indicates the surface of the basalt layer with a higher speed of about 6.8 km/s. The lower part of the crystalline crust is represented by a special subdivision of $K_3$ above the upper mantle and is associated with the intervals of its increased activity at various stages of evolution. In the transitional zones, structures $K_3$ act as quasi-elevations of the surface $M^*$.

The UPL model also includes different-scale and different-depth faults, dividing the medium into blocks of a hierarchical medium. Faults are distinguished taking into account violations shown in seismic sections, block parameters (size, density) and the position of the main surface.

2D models to the DSS profiles are constructed according to the method of seismic gravity modeling. In the starting density model, the density values of the sedimentary layerblocks, which has been studied in most detail by geophysical and geological methods, as well as of the consolidated crust and upper mantle within the measured longitudinal wave velocities, are set. The parameterization of the model is
performed taking into account the general correlation dependence $\sigma = f(V_p)$. However, the use of this dependence for all rocks of the lithosphere upper part may not be entirely correct, since the general dependence is determined by a set of parameters (lithostatic pressure, temperature, mineralogical composition of rocks, degree of metamorphism, etc.), approximately known for great depths. Therefore, when modeling, deviations from the general correlation dependence and density of blocks are allowed, which were adjusted within the acceptable values for each seismogeological floor.

For an example in fig. 1 shows a seismic-density model along the Pugachev – Beinau profile.

**Figure 1** Seismic-geological density section of the lithosphere upper part along Pugachev-Beinau DSS profile.

The main section surfaces (1–7): 1 – the roof of the first seismo-geological floor lower megacomplex (SGF); 2 – the roof of the ancient crystalline basement; 3 – the roof of the third SGF, possibly proto-crust; 4 – intermediate boundary of the second SGF; 5 – reflecting boundaries of the crystalline crust; 6 – transitional mega-complex in the lower crust; 7 – the main seismic-geological section M (a), position of the upper boundary of the earth's crust sole at the elevation of the interface M (b); 8 – alleged discontinuous violations: a - dividing, mainly blocks of the earth's crust and upper mantle, b - mainly in the upper and middle parts of the crust; 9 – values of the estimated density of blocks in g/cm$^3$.

The tectonic zoning of the UPL under the cut is shown in Fig. 2.

The uniqueness of the depression, in addition to its large size and non-linear shape, lies in the anomalous structural features of the lithosphere upper part. Previously, seismic information on the Pugachev-Beynau profile concerned only the earth's crust with rather limited data on its bottom (Artyushkov, Egorkin, 2005). This information was confirmed and corrected in the process of gravity modeling and, more importantly, data were obtained on significant heterogeneities of the upper mantle tops with density variations of $\sigma = 3.30-3.37$ g/cm$^3$. As can be seen from fig. 1, crust of the eastern part of Pre-Caspian depression is broken by deep faults of various directions. Seismogeological floors of the model with sustained values of speed and density are separated by surfaces $K_{01}$, $K_{02}$, $K_{03}$, $M^*$, $M$. Starting
from 290 km to the south, a transition zone between the lower crust and the upper mantle is clearly distinguished in the section. The weighted average densities of the crystalline crust of the seismic-geodensity model in the interval 290-470 km are calculated. The density of the submeridional II and sublatitudinal V, VI dislocations (≈ 3.04 g/cm³) of the crystalline crust differs significantly from the density of the central megastructure A1 of the southeastern margin of EEP and subdivision B, respectively, 2.85 g/cm³ and 2.93 g/cm³. The increase in density in the boundary structures is generally consistent with the hypothesis (Artyushkov E.V., Egorkin A.V., 2005) about eclogitization of the lower part of the crystalline crust due to intramantine processes that lead to an increase in physical parameters (V, σ) to mantle values.

Figure 2 The scheme of tectonic zoning of the lithosphere upper part of the eastern part of Pre-Caspian basin (compiled by V. S. Druzhinin).

Legend: 1 – large sublatitudinal dislocations, corresponding mainly to deep shifts: V – Volgograd-Emba deep shift; VI – Aral-Murgab, possibly the continuation of the Ural-Aral (I), but already as delimiting more southern platforms; 2 – border planetary-regional structures: I – Priuralsko-Aralskaya, II – Kaltasinsko-Caspian; III – Pachelsko-Akkolskaya; IV – Central Ural; 3 – the western border of the UFS; 4 – contours of border structures; 5 – deep faults (a), deep faults characterizing the northern end of the Pre-Caspian syncline; 6 – contours of ring structures, corresponding mainly to salt formations against the background of deep tectonics; 7 – DSS profiles: 1 – Krasnodar-Emba, 2 – Manysh-Karachaganak, 3 – Pugachev-Beinau, 4 – Temirtau-Kuibyshev, 5 – Cheklar-Volgograd, 6 – Emba-Orenburg.

Results
1. For the first time, a tectonic scheme of the upper part of the PCD lithosphere was created, including the southern margins of the VEE and UFS in the scale 1: 2 500 000, which allowed a new approach to solving the main problems associated with the nature of the formation of PCD (Fig. 2).
2. It is established that the basis of the PKV is the articulation of several large structures belonging to several ancient platforms, between which there are border structures that separate them with anomalous features of the deep structure. The main features of the platform boundary structures corresponding (in geological terms) mainly to aulacogens and depressions are the transformation of mainly the lower part of the ancient crust. Rocks due to the activation of mantle processes change the composition and physical parameters, approaching mantle values. The transformation process is manifested in seismic sections by quasi-elevation of the M surface (M' is the new boundary in the presence of a more deeply submerged M) and is accompanied by an increase in the thickness of sedimentary and subplatform deposits up to 20–22 km with a decrease in the proto-crust.

According to the results of our analysis (Druzhinin et al., 2019a, 2019b, 2019c), the ancient Lower Archean basement is almost universally present in the Caspian depression, which denies the presence of a granite-free crust (Aplonov, 1995, Artyushkov, Egorkin, 2005).
3. In accordance with the compiled scheme, the foundation of the East Caspian region is represented by the southeastern margin of the EEP, which is subdivided into three megablocks: A1 – Central (Middle) megastructure combines mainly ancient structures of the crystalline crust of the South Tatar vault. A2 – East (Bashkir-Orenburg) megastructure, the foundation of which is represented by the Lower Proterozoic and Riphean folded complexes. A3 – Western (Volga) megastructure.

In the east of the PKD is the Ural fold system: C1 is the western part, C2 is the southern part of the Central Ural megazone. Units B, D may correspond to the Arabian-Iranian ancient platform, represented by the Mediterranean belt and to the Turanian plate.

The border zones I – IV of submeridional orientation between megastructures are indicated in the scheme: I – Priuralsk – Aral, corresponding to 49–50º N the depression system of the Pre-Ural trough with salt tectonics (Solikamsky, Yuryuzansko-Sylvensky and Mrakovsky) between units A2–C1, to the south - the eastern border of the Mediterranean belt as part of two units (B and D); II – Kaltasinsky-Caspian between divisions A1–A2 and B; III – Pachelmsko-Akkolskaya between A1–A3 and B; IV – Central megazone (Magnetogorsk deflection), allocated within the UFS.

Sublatitudinal deep dislocations: V - Central structure, probably a deep shear of complex configuration, composed of several segments. Volgograd – Emba shift at latitudes 48–50º N installed according to the features of the deep structure and corresponds to the southern border of the EEP and the UFS; VI - border structure with a significant eastward shift, distinguished within the Turanian plate.

The northern part of the PCD is tectonically represented by two sub-latitudinal deep faults and the crystalline basement is gradually stepped down towards the central part of the depression.

Conclusions
The results of studies of the geostuctures deep structure of the Ural region and the Pre-Caspian depression specify in the regional plan the role of mantle activity in the transformations of the lower crust. At the same time the current position of the deep interfaces of the lithosphere upper part in some cases may not correspond to their ancient level.

The tectonic factor is decisive in the formation and evolution of the Pre-Caspian depression, which is reflected in the modern model of the upper part of the lithosphere. It is necessary to continue such studies to draw up a single model of the Pre-Caspian depression. This will make it possible, using the example of this structure, unique in geological and mineralogical terms, to reveal the role of deep criteria for solving such problems.

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