About a role of process of an isostasy in formation of a sedimentary cover of Greater Caucasus, its folded structure and a mountainous uplift (the factor analysis)

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The reality of natural processes of formation of sedimentary basins with the subsequent formation of folded and faulted structure in layered complexes and the uplift of mountains has to be reflected in regular changes of many parameters that have relation to structure and to character of development. Use of methods of statistics for the analysis of such parameters in this case will give material for a suggestion of the realistic models. This task has been solved for the sedimentary cover of Greater Caucasus by new methods of structural geology. The region is well studied, but there are different interpretations of its history of development and structure [Saintot et al., 2006; Leonov, 2007]. There are materials of the detailed structural cross-sections with a total length about 500 km, suitable for such researches [Yakovlev, 2015].

Among important parameters of structure the dimension of fold-related shortening in large blocks of rocks has to play a key role in the geodynamics study. For restoration of pre-folded structure of a sedimentary cover and for definition of important data of modern structure, the method of "geometry of folded domains" was used [Yakovlev, 2009]. The system of hierarchy of seven levels which is uniting objects of the different size from the deformed grains (the 1-st level) and usual folds (2nd one) to the folded systems of type of Greater Caucasus (6th) and mobile belts (7th level) was one of theoretical bases of the method. "Folded domains" (the third level, modern width about 1-2 km along a profile, unites packages of layers with a thickness of 0.5-2 km) and “structural cells” (the fourth level, width of 3-7 km, embrace a sedimentary cover of 10-15 km thickness) participated in measurement of shortening and in a restoration of pre-folded and modern structure. Deformations of "domains" are described by a strain ellipsoid with which the measured parameters of folds are compared, such as an inclination of the axial plane of folds, interlimb angles of folds, an inclination of an envelope plane of folds and other (fig. 1A). Three kinematic operations were applied in a restoration of the domain up to their pre-folded state (fig. 1 B): 1) – rotation (to a state of II), 2) horizontal simple shearing (to a state of III), 3) horizontal lengthening or clean shearing (to a state of IV). As a result, the segment of the line of a profile obtains other length and an inclination in horizontally layered medium. Thereafter all domains were united, taking into account displacements on faults.

“Structural cells” were allocated by aggregation of domains so that their general width in a pre-folded state approximately was equal (or some lesser) to the thickness of entire sedimentary cover. The relation of width of modern structure and pre-folded one is calculated as the value of shortening of a “structural cell”. For the subsequent calculations, the full thickness of a sedimentary cover, depth of the line of a profile of domains in stratigraphic model (based on age of rocks and thicknesses of deposits) and altitude of line of cross-section are used. It allows calculating the depth of sole of the cover (i.e. depth of basement top), conditional height of a cover top and an eroded part of sedimentary rocks (fig. 2, the stage 3).

For calculations, the most general model of development of the region, which is hypothetical partly, was also used (fig.2). Entire thickness of sedimentary cover was accumulated for the end of stages 1. At a stage 2, the folding with complete shortening took place without uplift and erosion of top of the cover. At the stage 3, the uplift and erosion of the upper part of sediments occurred (fig. 2). For 24 profiles, 505 domains were selected and then were integrated in 78 structural cells. For all cells, values of next six parameters were measured (*) or calculated: (1) the initial thickness of the sedimentary cover or depth of basement top (DBT) at a stage 1 (b1*); (2) values of shortening (Sh*); (3) DBT at a stage 2 after shortening (b2); (4) DBT at the

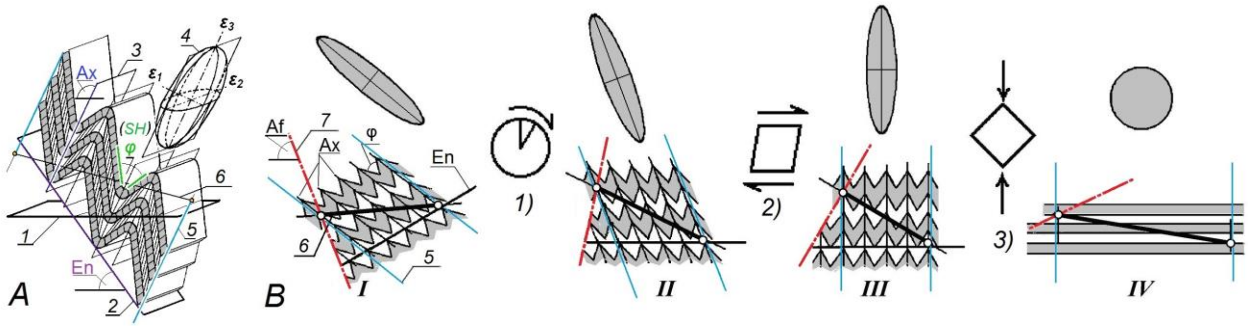

Fig. 1. Folded domain (A) and procedures of restoration of its pre-folded state (B) [Yakovlev, 2009].

1 – horizontal plane; 2 – an inclination of initial layering (En – dip angle); 3 – the fold axial plane (Ax – dip angle); 4 – strain ellipsoid (φ – interlimb angle, i.e. shortening value); 5 – boundaries of domains; 6 – length and angle of tilting of segment of cross-section line for the domain; Af – dip angle of fault plane.

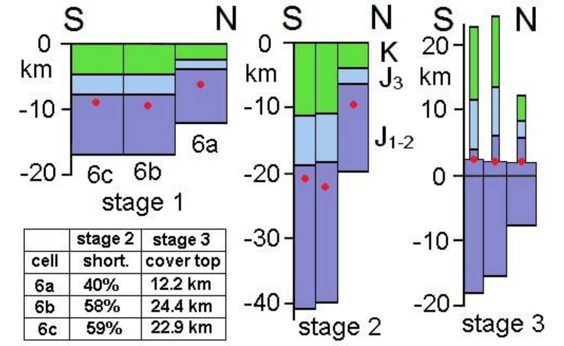

Fig. 2. Stages of structural cell development and calculations of parameters. Tfan zone.

stage 3 after an uplift of mountains (b3); (5) amplitudes of a neotectonic uplift (b3-b2*); (6) differences of depths of the basement between stages of 1 and 3 (b3–b1). The matrix of correlations for these parameters was calculated. The strong pair correlations, essential to understanding of processes of structure formation, were found, for example, (2/5) R = 0.818; (2/6) R = -0.461; (1/6) R = 0.379; (1/2) R = -0.023; (1/4) R = 0.708. It was also revealed at the qualitative level, that the depth of basement top in the modern structure in general tends to keep that level, which it acquired at the end of sedimentation. For understanding of a relation how parameters are connected to processes of structure formation, a factor analysis was used [Yakovlev, Gorbatov, 2016], in which pair correlations are not lost, but more general processes are important (table 1).

It was revealed that all data set is explained by two factors (summarized weight is 87%). The most significant factor, F1, is connected with the shortening value (2). The basement depth after a folding formation (3) and amplitude of an uplift (5) depends on it. The second factor F2 is connected with the initial depth of the basement (1) and it is interpreted as action of an isostasy. Modern depth of the basement (4) and a difference of depths of the basement (6) directly depends on it. Process of folding formation and of depended from shortening a new depth of basement top (parameter 3, loadings F1 0.736 and F2 0.665) is connected with influence of both factors. Participation of an isostasy in formation of structure should be connected with changes of density of rocks of crust up to density of mantle rocks in such large volumes, which are not stipulated by modern geodynamic models.

Table 1. Factor loadings for parameters

Parameters, (*) = “measured”		Factor loadings F1	Factor loadings F2
1	b1*	0.022	**0.790**
2	Sh*	**0.938**	-0.195
3	b2	**-0.736**	0.665
4	b3	-0.158	**0.982**
5	b3–b2*	**0.957**	0.050
6	b3–b1	-0.219	**0.853**
Weight %		60	27

Based on a supposition of the existence of permanent isostatic balance in the nature, an approximate calculation of changes of thickness of a crystalline part of crust for several stages of development of Greater Caucasus according to observed depths of the sea, thicknesses of sedimentary rocks and the shortening value was made for Chiaur (southern part of Caucasus in center) and Tfan (axial part of South-Eastern Caucasus) zones. Basal conglomerates of the bottom of entire sedimentary cover (Sinemurian) fix the 40 km thickness of crystalline continental crust. Fast immersion of structure and the beginning of accumulation of deep-sea (-3 km?) non-carbonated pelites of Lower Jurassic since Pliensbachian was followed by destruction of crystalline crust up to 25 km of thickness. At the end of process of accumulation of sediments of 15 km of thickness in the Eocene at the shallow-water sea, the thickness of crystalline crust has been further decreased on 11.5 km up to 13.5 km. The horizontal shortening of blocks in 50% (double), the uplift and an erosion of the top part of a sedimentary cover showed the calculated thickness of crystalline crust in 29.5 km thickness, that is on 2.5 km more, than simple increase in its thickness due to deformation. Rocks of the initial Moho level (for beginning of Jurassic, 40 km) exist on a depth about 100 km now. Thereby, it was defined that the volume of a crystalline part of crust, which got mantle density, is up to 60% of initial thickness. Processes of folding formation and of the shortening together with neotectonic uplift and erosion, which exist under the control of isostasy, could not take place without such transformations of densities of rocks.

Leonov Ju. G., (ed.). 2007. The Greater Caucasus in the Alpine Epoch. Moscow: Geos. 368 P. (in Russ.)

Saintot A., Brunet M.-F., Yakovlev F., Sébrier M., Stephenson R., Ershov A., Chalot-Prat F. & Mccann T. 2006. The Mesozoic–Cenozoic tectonic evolution of the Greater Caucasus. European Lithosphere Dynamics. (eds. Gee, D. G., Stephenson, R. A.). Geological Society, London, Memoirs. 32. pp. 277–289.

Yakovlev F.L. 2009. Reconstruction of Linear Fold Structures with the Use of Volume Balancing // Izvestiya, Physics of the Solid Earth. Vol. 45. No. 11. pp. 1025–1036.

Yakovlev F. L. 2015. Multirank strain analysis of linear folding on the example of the Alpine Greater Caucasus. Doctoral habil. thesis. Moscow: IPE RAS. 2015. Manuscript. 472 P. (in Russ.) http://yak.ifz.ru/

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