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ABOUT AN IDENTIFICATION OF GEODYNAMIC PROCESSES OF GREATER CAUCASUS FORMATION WITH A USE OF A FACTOR ANALYSIS OF PARAMETERS OF ITS FOLDED STRUCTURE

Fedor Yakovlev and Yevgeni Gorbatov,
Institute of physics of the Earth, RAS,
Moscow, Russia, yak@ifz.ru

1. INTRODUCTION

Report is focused on identifying geodynamic mechanisms leading to formation of large crustal blocks in nature. A specific feature of our study is statistical analysis of the data obtained by the methods of neotectonophysics and structural geology. The analysed material included 24 detailed structural profiles across the central part of the Greater Caucasus. The Meso-Cenozoic sedimentary cover, that was intensely folded in the Oligocene and Early Miocene, is 1015 km thick. A structure, balanced in strain values and sediments volumes, was reconstructed for three stages in the development of the folded structure: pre-folded, folded and post-folded, post-uplift. The "geometry of folded domains" method was used. For this purpose, 505 structural domains were identified in the detailed structural sections, the pre-fold state for every domain were reconstructed, and all the domains were compared. Overall, 78 structural cells (folded domains) were based on material indicators measurable in the folds, forming the folded structure. Each structural cell was characterized by six parameters: an amount of shortening, depths of the basement top in the pre-folded, post-folded, and modern stages (i.e. stages 1,2, and 3, respectively); a calculated position of the eroded top of the sedimentary cover (i.e. amplitude of orogenic uplift); and a folding type (symmetric or asymmetric) for stages 1 and 3. For 78 structural cells, the shortening is about 50 % on average (from 210 % to 67 %). An average modern calculated depth of the basement top is 3.1 km (from 2.2 to 31.7 km). The amplitudes of uplifting and of the erosion of top of the sedimentary cover are comparable and are about 1.5 km. Steady combinations of these values forming certain structures have been detected on the studied areas. It was found that the depth of the basement top in stage 3 (modern) has tendency to keep the value similar to the depth acquired in stage 2 (post-folding). Thus, the folding process was mostly isotatic. A number of estimated high values of the past correlations have a genetic meaning.

Using the factor analysis (as generalization of pairs correlations), we detected two factors related to the shortening and to the amplitude of the orogenic uplift, accounting for 65 % of the total variance of the parameters for the folded volumes of the crustal blocks. The factor "isostasy" in such kind was not taken into account in geodynamic models earlier. Factor F2 (shortening, 40 % weight) depends on the amount of shortening and is responsible for amplitudes of uplifting.

The report contains the following parts:

2. THE ALPINE GREATER CAUCASUS.
The sedimentary cover of the Caucasus is formed by terrigenous and carbonate-terrigenous thin-layer thicknesses from the Lower Jurassic up to the Eocene, with the maximum thickness of 10-12 km, crumpled in folds sizes from 15-30 to 150-200 km, formed in the Oligocene and Early Miocene. From Oligocene; since a Miocene, the mountain construction began to uplift here. For the analysis, 24 detailed structural profiles with a total length more than 500 km, divided into "folded domains" (only 505) and 78 of "structural cells", were used.

3. METHOD OF COMPILATION OF MODEL OF THE BALANCED STRUCTURE OF SEDIMENTARY COVER.
For creation of the structure, balanced on volume of a sedimentary cover, we developed the method of the "geometry of folded domains" was used [Yakovlev, 2009; 2017]. The inclination of an envelope plane of folds, an inclination of an axial surface of folds, an interlimb angle of folds and other parameters were measured. In domains, homogeneous in structural and mechanical properties, a lengthening allowed to restore pre-folded structures of such domains (in width and allocation in a sedimentary cover), and then each profile entirely. In the pre-folded profiles, structural cells were allocated. For these cells, shortening values and the pre-folded and modern depth of a basement top, the calculated position of an eroded top of the sedimentary cover and the amplitude of a neotectonic uplift were defined.

4. THE MODEL OF THE BALANCED STRUCTURE OF GREATER CAUCASUS.
Shortening values for structural cells of Greater Caucasus varied from 67% with a minimum (for a value of 67%). The modern depth of a basement top had mean value of -13 km, at dispersion of -2.2 ÷ -31.7 km; amplitudes of an uplift and erosion of a top of a sedimentary cover for large blocks were 9 to 19 km. Distribution of the specified variables in a space has shown that they are not casual and are steady and reflecting natural regularities. Using these results, the model of a structure of east part of Greater Caucasus, which showed inevitability of change of density of rocks of crust to density of rocks of an upper mantle in the structure bottom, was constructed [Fig. 7-1].

5. MANIFESTATION OF AN ISOSTASY IN FOLDED STRUCTURE OF GREATER CAUCASUS.
As a result of preliminary studying of materials of the balanced model of a sedimentary cover of Greater Caucasus, some regularities were found.

1) Values of a modern depth of the modern basement top for 78 structural cells (-15 and -13 km) on average is close to mean value of depth of a basement top at a pre-folded stage of their development (i.e. thickness of a sedimentary cover, ~13 km) that professionally it is possible to connect with action of an isostasy. 2) Values of a modern depth of a basement top and profiles depth of a basement top have small variations from the initial value (from 3.3 to -3.3 km, on maximum). Along a section, for a part of profiles there are very larger deviations (from -15 km up to +7 km). In these profiles, the southern part of a basement top is lowered, and, regardless of a structural type of some part of Greater Caucasus, it occurs in general, the same regularity, the strong relative immersion of the southern part of structure, remains.

6. RESULTS OF A FACTOR ANALYSIS.
For the key six parameters of structures, the matrix of correlations was constructed. Some very great values of correlation, making genetic sense for some couples of parameters, were determined. For example, the value of correlation coefficient for shortening and amplitude of an uprising was 0.819. The factor analysis of data array revealed two factors, accounting for 65 % of variance of data. The first geodynamics mechanisms of formation of structure of Greater Caucasus. Factor F1 has a weight (a share of all correlative relations) in 47%, which depends on the initial thickness of a sedimentary cover; this factor dictates the actual calculated depth of a basement top (correlation with it is -0.90). Factor F2 (40 % weight) depends on the amount of shortening and is responsible for amplitudes of uplifting.

7. DISCUSSION
Several topics, which have relation to processes of "shortening" and "isostasy", are discussed:
7-1. Scale of studied structures in relation to factors
7-2. What two factors are: a hypothesis or the reality?
7-3. Vertical movements of blocks of earth crust and factor of "isostasy"
7-4. Ratio of processes of "shortening" and "isostasy"
7-5. Importance of result for a geodynamic modelling

8. CONCLUSIONS.
1) The statistical research of parameters of the balanced model of a sedimentary cover of Greater Caucasus revealed a number of important pair correlative relations, which make geodynamic sense. Use of a factor analysis showed an existence of two rather independent processes (factors), the based to isostatic alignment of structure on the basement top depth (F1, "an isostasy", the table 6-4) and with the shortening value (factor F2, "a shortening"). The factor "isostasy" in such kind was not taken into account in geodynamic models earlier. Factor F2 (shortening, 40 % weight) depends on the amount of shortening and is responsible for amplitudes of uplifting.

2. THE ALPINE GREATER CAUCASUS

Fig. 2-1. Locations of the studied areas in the schematic map of the geological and tectonic structure of Greater Caucasus (modified after the geological map in [Sokolov; Tsereteli, 1999]). The map shows the Scythian plate, Transcaucasian Median Massif, and Lesser Caucasus. 1 – sedimente, 1 – Quaternary, 2 – Neogene and Paleogene, 3 – Mesozoic, 4 – Paleozoic, 5 – Precambrian, 6 – faults, 7 – boundaries of structural boundaries (DT – Pshekish-Tyrgovskaya Fault, RT – Racha-Lechkhumi Fault), 8 – in Greater Caucasus (TP – Main Caucasian Fault), 7 – four sectors, according to [Sholpo, 1978]: CSK – North-Western Caucasus, ESK – Central Caucasus, BK – Eastern Caucasus, IOBK – South-Eastern Caucasus; 8 – studied areas (1 – CSK, 2 – Chinar tectonic zone, 3 – IOBK: Shakhdag and Tfan tectonic zones).

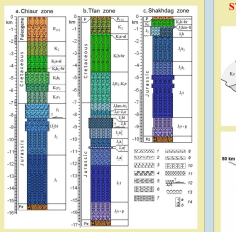


Fig. 2-2. Stratigraphic columns for three tectonic zones: a. Chinar zone (Central Caucasus, area 2, fig.2-1), b.Kt – Tfan and Shakhdag zone (South-Eastern Caucasus, area 3)

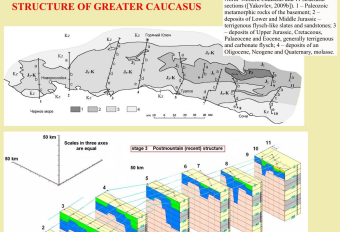


Fig. 4-2. The present day structure of the North-Western Caucasus (stage 3) shown in the anomorectic projection on 42 structural cells with the new thickness of the main stratigraphic units, which increased because of shortening (Yakovlev, 2015a), with changes).

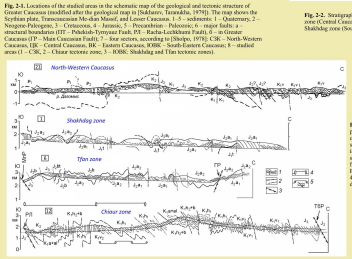


Fig. 2-3. Example of a structural section for different parts of Greater Caucasus. Division of the structure on two kind of tectonic objects – domains and structural cells – are shown (profile 12, etc. Kosbulta, Tfan, Chinar). Main faults, hydrographic elements, stratigraphic boundaries, 2 – large and medium-size faults, 3 – faults at the margins of tectonic zones PT – Racha-Lechkhumi Fault, TOP – Tfir thrust; 4 – structural cells and their boundaries; 5 – folded domains and their boundaries.

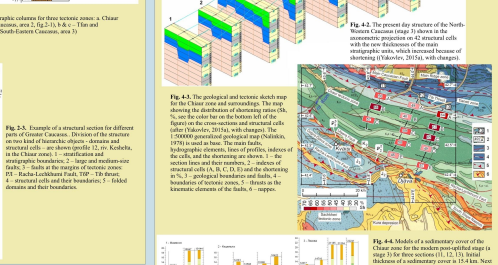


Fig. 4-3. The geological and tectonic sketch map for the Chinar zone and surroundings. The map showing the distribution of shortening ratios (Sh, %, see the color bar on the bottom left of the figure) on the cross-sections and structural cells (after [Yakovlev, 2015a], with changes). The 1:500000 generalized geological map (Nalitskiy, 1978) is used as base. The main faults, hydrographic elements, lines of profiles, indexes of the cells, and the shortening are shown. 1 – the section lines and their numbers, 2 – indexes of structural cells (A, B, C, D, E) and the shortening in %, 3 – geological boundaries and faults, 4 – boundaries of tectonic zones, 5 – thrusts as the kinematic elements of the faults, 6 – nappes.

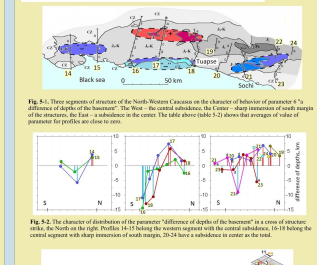


Fig. 4-4. Models of a sedimentary cover of the Chinar zone for the modern post-uplifted stage (a stage 3) for three sections (11, 12, 13). Initial thickness of a sedimentary cover is 15.4 km. Next parameters are shown: new width of all structural cells ("a", "b", "c", "d", "e"), new thicknesses of structural cells, the shortening in percents, shortening, and vertical movements of a position of all borders of the stratigraphic units in cells as a result of a neotectonic uplift. Amplitudes of the uplift is shown in each cell. Under the terms of model all erosion of upper part of sedimentary cover happened at a neotectonic stage. Vertical and horizontal scale are identical.

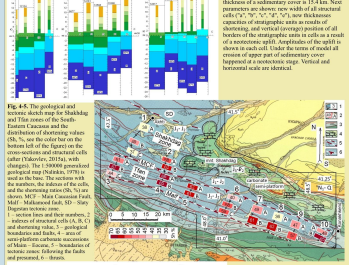


Fig. 4-5. The geological and tectonic sketch map for Shakhdag zone (area 3 on the South-Eastern Caucasus and the distribution of shortening values (Sh, %, see the color bar on the bottom left of the figure) on the cross-sections and structural cells (after [Yakovlev, 2015a], with changes). The 1:500000 generalized geological map (Nalitskiy, 1978) is used as the base. The sections with the numbers, the indexes of the cells, and the shortening in percents (%) are shown. MCF – Main Caucasian Fault, MdF – Malkasoud fault, SD – Sheki Degerlan tectonic zone.
1 – section lines and their numbers, 2 – indexes of structural cells (A, B, C) and shortening value, 3 – geological boundaries and faults, 4 – area of semi-platform carbonate successions of the Lesser Caucasus, 5 – nappes in tectonic zones following the faults and presumed, 6 – thrusts.

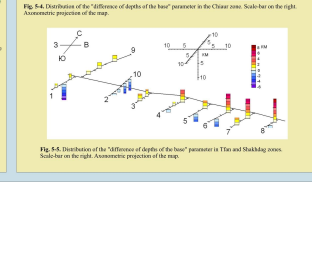


Fig. 4-6. The present day structure of the Shakhdag and Tfan zones (stage 3) shown in the anomorectic projection on 23 structural cells with the new thicknesses of the main stratigraphic units, which increased as a result of shortening (Yakovlev, 2015a), with changes). The eroded parts of the sedimentary cover are shown by the narrow columns in the air. 1 – Paleogene, 2 – Cretaceous, 3 – Upper Jurassic, 4 – Middle Jurassic, 5 – Lower Jurassic.

3. METHOD OF COMPILATION OF MODEL OF THE BALANCED STRUCTURE OF THE SEDIMENTARY COVER

Fig. 3-2. Position of a strain ellipsoid in a fold (after [Yakovlev, Voitenko, 2005]). The model of a fold of packs of layers (hierarchical level II) showing the general deformation: 1 – axial plane, 2 – hinge line; and ellipse of deformations for separate layers (3 – incompetent and 4 – competent). Axes of common ellipsoid: x1=1.00>2=1.3, x2=1.00>1=1.6, x3 = 1.0>0=0.47.

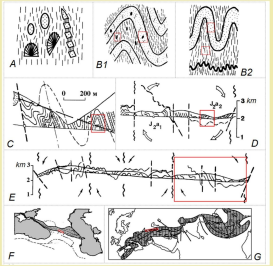


Fig. 3-1. Hierarchy of structures of the linear folding (of hinterland) (on [Yakovlev, 1997; Rebetsky, et al., 2004], with changes).
A – grains or inclusions (the I level, intra-layer); B – separate folds (the II level, a layer, two layers, two types of objects are shown: folds of packs of layers of a layer, B1, and single viscous layer fold, B2); C– folded domains (the III level, large packs of layers or lithologic complexes); D– structural cells (the IV level, a sedimentary cover entirely); E – tectonic zones (V level, crust entirely); F – folded systems or mega-anticlinorium (VI level, lithosphere in general?); G – the mobile belts entirely (the VII level, all upper mantle?)

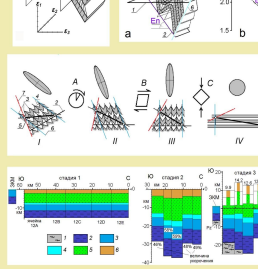


Fig. 3-3. The folded domain and the strain ellipsoid in the folded structure ("a" after [Yakovlev and Voitenko, 2005]); the structural material is the detailed profile of the Greater Caucasus (Kosbulta tectonic zone). Main structure, 3 domains, part of section 7, Tfan zone, East Southern Caucasus (Yakovlev, 2015a, 2015b). a – The axes of the ellipsoid for the fold: lengthening (1), intermediate (2), shortening (3). Main parameters of the domain (i.e. a combination of several folds): 1 – horizon plane; 2 – surface of the envelope plane and its dip, Fn; 3 – axial plane and its dip, Ax; 4 – strain ellipsoid, which value of shortening (SH) is measurable from the interlimb angle, e (SH=(1–cos90/=e2)/=100%); 5 – the segment of the profile within the limits of the domain, its length and dip; 6 – domain's boundary in the profile (parallel to the axial planes of the folds). b – Conventional signs for the same as in "a"

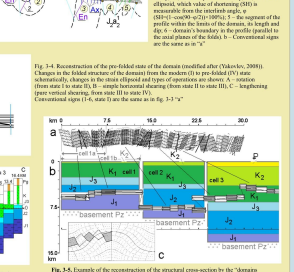


Fig. 3-4. Reconstruction of the pre-folded state of the domain (modified after [Yakovlev, 2008]). Changes in the folded structure of the domain) from the modern (I) to pre-folded (IV) state schematically; changes in the strain ellipsoid and types of operations are shown; A – rotation (from state I to state II), B – simple horizontal shearing (from state II to state III), C – lengthening (pure vertical shearing, from state III to state IV).
Conventional signs (1-6, state I) are the same as in fig. 3-3 "a"

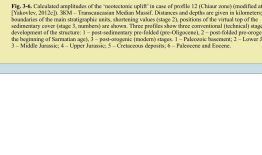


Fig. 3-4. Calculated amplitudes of the 'neotectonic uplift' in case of profile 12 (Chinar zone) (modified after [Yakovlev, 2012c]). 3630 – Transcaucasian Median Massif. Distances and depths are given in kilometres; the boundaries of the main stratigraphic units, shortening values (stage 2), positions of the virtual top of the sedimentary cover (stage 3, numbers) are shown. Three profiles show three conventional (technical) stages in the development of the structure: 1 – post-sedimentary pre-folded (pre-Oligocene); 2 – post-folded pre-orogenic (for the beginning of Sarmatian age); 3 – post-orogenic (modern) stages. 1 – Paleozoic basement; 2 – Lower Jurassic; 3 – Middle Jurassic; 4 – Upper Jurassic; 5 – Cretaceous deposits; 6 – Paleocene and Eocene.

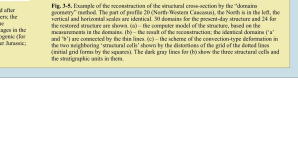


Fig. 3-5. Example of the reconstruction of the structural cross-section by the "domains geometry" method. The part of profile 20 (North-Western Caucasus), the North is in the left, the vertical and horizontal scales are identical. 30 domains for the present-day structure and 24 for the restored structure are shown. (a) – the computer model of the structure, based on the measurements in the domains. (b) – the result of the reconstruction; the identical domains ('a' and 'b') are connected by the thin lines. (c) – the scheme of the conversion-type deformation in the two neighboring 'structural cells' shown by the distortions of the grid of the dotted lines (initial grid forms by the squares). The dark gray lines for (b) show the three structural cells and the stratigraphic units in them.

4. THE MODEL OF THE BALANCED STRUCTURE OF GREATER CAUCASUS

Fig. 4-1. Schematic geological map of the North-Western Caucasus and 11 structural sections (1[Yakovlev, 2009b]). 1 – Paleozoic metamorphic rocks of the basement; 2 – deposits of Lower and Middle Jurassic – terrigenous flysch-like slates and sandstones; 3 – deposits of Upper Jurassic, Cretaceous, Paleocene and Eocene, generally terrigenous and carbonate flysch; 4 – deposits of an Oligocene, Neogene and Quaternary, molasse.

Table. Average values of **depths of basement top (DBT)**, amplitudes of a neotectonic uplift and other parameters for three stages of development of the North-Western Caucasus (42 cells) and for three zones of East half of Greater Caucasus (36 cells). After [Yakovlev, 2015a].

Regions	Shortening value (Sh) (%)	Pre-folded depth (DBT) (km)	Post-folded depth (DBT) (km)	Present day depth (DBT) (km) (stage 3, fig. 4-2)	Amplitude of neotectonic uplift (km)	Difference of depths (Pre-Post) (km)
North-Western Caucasus	35%	-13.38	-22.2	-13.25	8.9	0.13
Shakhdag, Tfin, Chiaur zones	55%	-13.6	-31.7	-15.1	16.6	-1.5

Table. Average values of the parameter (6) "difference of depths of the basement" for profiles of the North-Western Caucasus and values of shortening (without short sections 19, 22, 24).

Profile	14	15	16	17	18	20	21	23	average
Difference of depths (average), km	-0.7	0.7	-3.0	-0.5	-5.5	3.6	0.8	-0.4	0.13
Shortening (%)	16	12	33	32	52	40	38	32	35%

Table. 5-1.

Fig. 5-1. Three segments of structure of the North-Western Caucasus on the character of behavior of parameter 6 "a difference of depths of the basement". The West – the central subsidence, the Center – sharp immersion of south margin of the structures, the East – a subsidence in the center. The table above (table 5-2) shows that averages of value of parameter for profiles are close to zero.

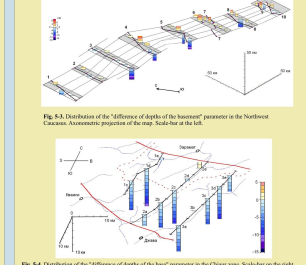


Fig. 5-2. The character of distribution of the parameter "difference of depths of the basement" in a cross of structure strike, the North on the right. Profiles 14-17 belong the western segment with the central subsidence, 16-18 belong the central segment with sharp immersion of south margin, 20-24 have a subsidence in center as the total.

Fig. 5-3. Distribution of the "difference of depths of the basement" parameter in the Northwest Caucasus. Axonometric projection of the map. Scale-bar at the left.

Fig. 5-4. Distribution of the "difference of depths of the base" parameter in the Chiaur zone. Scale-bar on the right. Axonometric projection of the map.

Fig. 5-5. Distribution of the "difference of depths of the base" parameter in Tfan and Shakhdag zones. Scale-bar on the right. Axonometric projection of the map.

5. MANIFESTATION OF AN ISOSTASY IN FOLDED STRUCTURE OF GREATER CAUCASUS

	Parameters (DBT – Depth of basement top)	
1	DBT, stage 1 (pre-folded)	b1*
2	shortening value	Sh*
3	DBT, stage 2 (post-folded), km	b2
4	DBT, stage 3 (post-uplift), km	b3
5	Amplitude of neotec. uplift, km	b3-b2*
6	Difference DBT (stages 3-1), km	b3-b1

6. FACTOR ANALYSIS

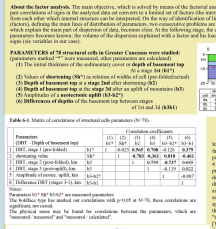
About the factor analysis. The main objective, which is solved by means of the factorial analysis, is two – data of a large number of variables (parameters) can be replaced with a smaller number of factors, which will be able to reproduce most of the relationships among these data (or their correlations), which initially observed variables are interrelated. On the way of identification of limited number of internal communications (factors), defining the main lines of distribution of parameters, two consecutive problems are solved. At first, the number of factors, which explain the main part of dispersion of data, becomes clear. At the following stage, the characteristic of factors for the form of two parameters becomes known: the volume of the dispersion explained with a factor and his loadings (linear correlations) on each of initial signs (six variables in our case).

PARAMETERS of 78 structural cells in Greater Caucasus were studied:
(parameters marked ******* were measured, other parameters are calculated)
(1) The initial thickness of the sedimentary cover or **depth of basement top** At a stage **1st (b1*)**
(2) Values of **shortening (Sh*)** as relation of widths of cell (pre-folded/actual)
(3) **Depth of basement top** at the **stage 2 (b2)** after a folding
(4) **Depth of basement top** at the **stage 3d** after an uplift of mountains (**b3**)
(5) Amplitudes of a **neotectonic uplift (b3-b2*)**
(6) **Difference of depths** of the basement top between stages of 1st and 3d **(b3b1)**

Table 6-1. Matrix of correlations of structural cells parameters (N=78).

Parameters (DBT – Depth of basement top)		(1) b1*	(2) Sh*	(3) b2	(4) b3	(5) b3-b2*	(6) b3-b1
1	DBT, stage 1 (pre-folded)	b1*	1	-0.832	**0.505**	**0.708**	-0.126
2	shortening value	Sh*		1	**-0.701**	**-0.301**	**0.018**
3	DBT, stage 2 (post-folded), km	b2			1	**0.556**	**0.755**
4	DBT, stage 3 (post-uplift), km	b3				1	-0.139
5	Amplitude of neotec. uplift, km	b3-b2*					1
6	Difference DBT (stages 3-1), km	b3-b1					-0.067

Notes:
Parameters b1* b3 b3-b2* are measured parameters
The boldface type has marked out correlations with p<0.05 at N=78, these correlations are significant, not casual.
The physical sense may be found for correlations between the parameters, which are "measured / measured" and "measured / calculated".



In primary qualitative analysis of material, the fact has been found out that values of parameters 1 (base roof depth at a stage 1) and 4 (base depth at a stage 3) on average in profiles seek to be very close mutual other, despite considerable deviations of their difference along profiles from zero. The assumption of action of "Isostasy" which seeks to keep this depth at the basis rude in spite of the fact that reduction of structure in the course of a folding "sinking" it, and during "the neotectonic mainly" – "uplifting" [Yakovlev, 2015]. Also the conclusion was drawn that "isostasy" is connected with essential changes of density of rocks of crust and a mantle [Yakovlev, 2012; 2015].

At the first stage of a statistical research of the received data array (78 objects), pair correlations between the listed parameters have been defined [Yakovlev, 2008; 2015]. Some correlations have shown very high values (**table 6-1, fig. 6-1**). There were all bases to believe that a part of such strong correlations makes genetic sense.

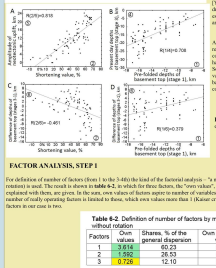


Fig. 6-1. Scatter plots for correlations of parameters 2/5, 1/4, 2/6, 1/6

FACTOR ANALYSIS, STEP 1

For definition of number of factors (from 1 to 3-4th) the kind of the factorial analysis – "a method of main components" (without rotation) is used. The result is shown in **table 6-2**, in which for three factors, the "own values", showing a share of the dispersion explained with them, are given. In the sum, own values of factors aspire to number of variables of the massif, in our case – to 6. The number of really operating factors is limited to three, which own values more than 1 (Kaiser criterion). The number of rail-life factors in our case is two.

Table 6-2. Definition of number of factors by method "main a component" without rotation

Factors	Own values	Shares, % of the general dispersion	Cumulative values	Cumulative dispersion, %
1	3.614	60.23	3.614	60.23
2	1.592	26.53	5.206	86.77
3	0.726	12.10	5.932	98.86

FACTOR ANALYSIS, STEP 2

The main result has been received by obtaining of factors by a method of "main a component" with orthogonal rotation - "Varimax" Geometrical sense of the method is based on consecutive identification of mutually orthogonal axes of a multidimensional cloud of initial variables (the dots are points of ends of axes coincide with the line of multidimensional regression), concerning which by rotation of this cloud dispersion of data is maximized. The good result can be considered such distribution when high loading of parameter on one factor is followed by low value for him on other factor. Such result facilitates interpretation of loadings. In addition to Varimax, several similar methods (Varimax Normalized, Biquartimax, Biquartimax Normalized) were used also. All results of such methods have close values of F1, F2 and loadings (table 6-3).

In a number of the previous publications [Yakovlev, Gorbatov, 2016; 2017a; 2017b], **the isocart result of factor analysis**, which has resulted from a technical mistake, **has been shown**.
The right results are such: **a factor 1 "Isostasy" has 46.6%, a factor 2 – "shortening" has 40.2%.**

Table 6-3. Loadings of parameters at different types of the factorial analysis (allocation of factors by method "main a component")

Variables	Without rotation		varimax		varimax normalized		Biquartimax		Biquartimax normalized	
			With rotation							
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
1	0.586	-0.520	0.790	0.022	0.791	-0.054	0.790	0.033	0.790	-0.030
2	0.747	-0.598	0.939	-0.190	0.940	-0.209	0.939	-0.208	0.938	-0.230
3	0.581	0.145	0.665	0.756	0.657	0.743	0.675	0.735	0.672	0.729
4	0.858	-0.502	0.882	-0.456	0.880	-0.469	0.884	-0.445	0.883	-0.449
5	0.406	0.742	0.080	0.917	0.097	-0.984	0.067	-0.984	0.067	-0.984
6	0.799	-0.373	0.953	-0.219	0.951	-0.228	0.956	-0.207	0.955	-0.211
Own values	3.614	1.592	2.796	2.410	2.775	2.431	2.824	2.362	2.816	2.390
Shares, % of disp.	**60.2**	**26.5**	**46.6**	**40.2**	**46.3**	**40.5**	**47.1**	**39.7**	**46.9**	**39.8**

Table 6-4. Factor loadings of structural cells parameters

Parameters (DBT – Depth of basement top)		Factor loadings F1	F2
1	DBT, stage 1 (pre-folded)	b1*	**0.790**	0.022
2	shortening value	Sh*	-0.195	**0.938**
3	DBT, stage 2 (post-folded)	b2	**0.665**	**-0.738**
4	DBT, stage 3 (post-uplift)	b3	**0.922**	-0.156
5	Amplitude of neotec. uplift	b3-b2*	0.005	**0.997**
6	Difference DBT (stages 3-1)	b3-b1	**0.883**	-0.219
	Own values (6 maximum in sum)		2.796	2.410
	Weights of factors (Shares % of the general dispersion)		**46.6**	**40.2**

Note: The boldface type has marked out high loadings (>0.7).
Parameters b1*, Sh*, b3-b2* are **measured** parameters and red colored factor loadings **0.982** are for **measured** parameters, blue colored **0.888** are factor loadings for **calculated** parameters.

Interpretation of a factor 2, F2.

In the second factor of F2 the key strong parameter is a shortening value (parameter 2, "Sh", loading 0.938). The basement top depth at a stage 2 is connected with it (parameter 3, "b2", loading -0.738); the calculated parameter) and arisen later, at a stage 3, the uprising amplitude (parameter 5, "b3-b2", loading 0.997); the measured parameter). This factor extracts with shortening of space. F2 factor weight in an explanation of dispersion is 40.2%, own value – 2.4. In former results, this factor was the first and had big weight.

Interpretation of a factor 1, F1.

In the factor F1, one of strong parameters (**parameter 1**, "b1", loading 0.790) is **the initial depth of a basement top** (the roof depth at a stage 1). Other parameters are calculated ones (**table 6-4**). It is the modern depth of a basement top (**parameter 4**, "b3", loading 0.922) and a difference of depths of the basement (**parameter 6**, "b3-b1", loading 0.883). The first factor is genetically connected with depth of the basement top, which has arisen at the end of a sedimentation stage, and it is responsible for preservation of its depth as a result of action of two long-time processes, – folding formation and mounains buildings, which are generally consecutive. In our opinion, **this factor contacts with action of "Isostasy" at which densities of rocks of crust and the upper mantle are changing.**
F1 factor weight in an explanation of dispersion is 46.6%, own value – 2.8. In results of former publications, this factor was the second and it had smaller weight.

7. DISCUSSION

7-1. SCALE OF STUDIED STRUCTURES IN RELATION TO FACTORS
As it has become clear at statistical researches, the found parameters of "structural cells" are connected with mechanisms of formation of larger structures covering entire crust and the upper mantle. These are the probability of the I and VI level of hierarchy of structures (structures of E, F, fig. 2-1; block 2). There are features of mechanisms "shortening of space" and "isostasy", which in their embracing, on time of several diverse stages of development of blocks of a crust and upper mantle, from an immersion and accumulation of sediments up to the mountain building. The factor of "isostasy" works all the time of development, the factor of "shortening" works only shortterm (during the Oligocene?).

7-2. WHAT TWO FACTORS ARE– A HYPOTHESIS OR THE REALITY?
Considering the statistical research and mechanisms of "shortening of space" and "isostasy", it is necessary to consider that their detection is statistically significant material has been made for the first time and that they represent, first of all, the set of the "necessary and sufficient" mechanisms describing formation of large structures. It means also that FINDING of TWO "FACTORS" OR "MECHANISMS" not the HYPOTHESIS, but BELONGS TO the OBSERVEDFACT.
It is possible to be sure, that essentially change of density of rocks of crust and the upper mantle at all three stages of formation of structure of Greater Caucasus is a fact in evidence. Existence of such changes (fig. 7-1) provides the appearance of modern structure of

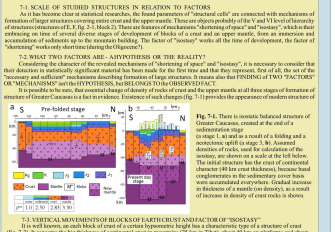


Fig. 7-1. Theme is isostatic balanced structure of Greater Caucasus, created at the end of a sedimentation stage
(a stage 1), and as a result of a folding and a post-folding stage (a stage 2). Assumed densities of rocks, used for calculation of the balanced structure, are shown in the table. The initial structure has the crust of continental character (40 km crust thickness), because basal metamorphosis in the sedimentary zone basis were accumulated everywhere. Gradual increase in thickness of a mantle (on density), as a result of increase in density of crust rocks is shown.

7-3. VERTICAL MOVEMENTS OF BLOCKS OF EARTH CRUST AND FACTOR OF "ISOSTASY"
Preliminary specification of a genetic ratio of two processes has been carried out. For this purpose we will analyze the parameter 3 ("b2"), it is depth of basement top after shortening, at a stage 2. The structural factor dictates loadings by Varimax method it is the only parameter having high values for both factors, 0.665 and -0.736 that is well visible in the figure 7-3. There is a strong correlation between "b2" and "shortening value" (parameter 2, "Sh", loading -0.701). It means, that "b2" is, in the first sight, it can be interpreted as an opposing as a result of direct action of shortening. However really this communication should be interpreted in some other manner.
Shortening of space at a stage 2 breaks sometimes an isostatic balance (or in parallel leads to change of density of rocks), but essential immersion of entire structure is a result of folding and shortening. This immersion not at once, but is restored as a result of a neotectonic uplift, which is a result of "isostasy" and which is a result of density of rocks of crust. Their concrete values for signs are shown in the table on the right: 0 – lack of relation, +1 – full relation. Red lines show the value of loading of a factor 0.7 taken for the level of statistical reliability.

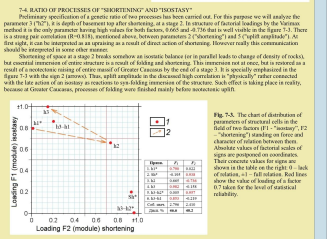


Fig. 7-2. Hypsometric curve and structures of crust for different case of altitude / water depth.

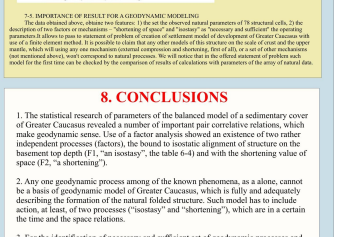


Fig. 7-3. The chart of distribution of parameters of structural cells in the field of two factors (F1 – "isostasy", F2 – "shortening"). Shows the character of relation between them. Absolute values of factorial scales of signs are postponed on coordinates. Their concrete values for signs are shown in the table on the right: 0 – lack of relation, +1 – full relation. Red lines show the value of loading of a factor 0.7 taken for the level of statistical reliability.

7-4. RATIO OF PROCESSES OF "SHORTENING" AND "ISOSTASY"
Preliminary specification of a genetic ratio of two processes has been carried out. For this purpose we will analyze the parameter 3 ("b2"), it is depth of basement top after shortening, at a stage 2. The structural factor dictates loadings by Varimax method it is the only parameter having high values for both factors, 0.665 and -0.736 that is well visible in the figure 7-3. There is a strong correlation between "b2" and "shortening value" (parameter 2, "Sh", loading -0.701). It means, that "b2" is, in the first sight, it can be interpreted as an opposing as a result of direct action of shortening. However really this communication should be interpreted in some other manner.
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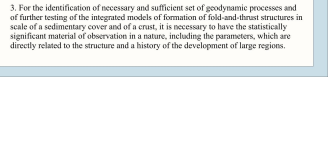

Fig. 7-4. Ratio of processes of "shortening" and "isostasy" (fig. 7-2). It concerns the structures of crust for different case of altitude / water depth. Values of parameters 2/5, 1/4, 2/6, 1/6 are shown in ocean plates of water depths of 4-6 km. This regularity allows to assume that if the block of crust experiences immersion of big amplitude, then the thickness of this crust will significantly decrease and vice versa. So, for example, in areas of passive continental margins on an eroded surface of the previous stage of development, continental deposits lay down. Continental sediments and volcanic-sedimentary oceanic deposits toward a top of sedimentary cover. The general thickness of such cover can be 10-15 km, the type of crust can be close to oceanic type, and nearby the purely oceanic crust can be at the same depth of an oceanic bottom. Such subsidence can speak about a change of density of crust rocks of Earth's crust, namely, 40 km thickness of continental type up to 15 km thickness of oceanic type (with replacing 25 km rocks densities from "crust" to "mantle" meanings).

7-5. IMPORTANCE OF RESULT FOR A GEODYNAMIC MODELING
The data obtained above, obtains two features: 1) the set the observed natural parameters of 78 structural cells, 2) the description of two factors or mechanisms – "shortening of space" and "isostasy" as "necessary and sufficient" the meaning parameters. It allows to pass to statement of problem of creation of settlement model of development of Greater Caucasus with the purpose of forecasting of the behavior of structures in future, taking into account the set of factors, which are the "necessary and sufficient" mechanisms, which will using any one mechanism (external compression and shortening, first of all), or a set of other mechanisms (not mentioned above), won't correspond to natural processes. We will notice that in the offered statement of problem such model for the first time can be checked by the comparison of results of calculations with parameters of the array of natural data.

8. CONCLUSIONS

1. The statistical research of parameters of the balanced model of a sedimentary cover of Greater Caucasus revealed a number of important pair correlative relations, which make geodynamic sense. Use of a factor analysis showed an existence of two rather independent processes (factors), the based to isostatic alignment on an existence of two rather independent processes (factors), the based to isostatic alignment of structure on the basement top depth (F1, "an isostasy", the table 6-4) and with the shortening value of space (F2, "a shortening").

2. Any one geodynamic process among of the known phenomena, as a alone, cannot be a basis of geodynamic model of Greater Caucasus, which is fully and adequately describing the formation of the structure. Such model has to include action, at least, of two processes ("isostasy" and "shortening"), which are in a certain time and space relations. To the identification of necessary and sufficient set of geodynamic processes and of further testing of the integrated models of formation of fold-and-thrust structures in scale of a sedimentary cover and of a crust, it is necessary to have the statistically significant observation material, including the parameters, which are directly related to