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Study of Comparative Roles of Thrusts and Normal Faults in the Collision Structure of the Greater Caucasus Based on Balanced Section of the Hinterland

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The Greater Caucasus (GC) is one of the sparse fold-thrust structure within the Alpine belt, which has weakly developed foreland areas and a well outcropped folded structure in its inner part (the hinterland). The hinterland of the GC has the thick (10-20 km) cover of deposits, which were deformed into numerous small folds. The deposits are mainly slate and carbonate flysh. The degree of the total Alpine deformation, metamorphism, and magmatism of the cover deposits is lesser than of the Alps. It allows us to reconstruct the development of the structure of the transitional zone between the hinterland and the foreland (between the meganticlinorium of the GC and blocks of Transcaucasus Massif, TM) more easy and reliably than in complicated regions. Of course, the accuracy of study of the sedimentation history and of the description of alterations of 3-D geometry of sediments volume are very important, because these two factors may be conclusive for the choice of geodynamic model.

The usual problem of the reconstruction of the folded structures is the complexity of the continuation of the folds and fault into the deep part of the structure (5-10 km and more) and into the upper part (into the air). The procedure of construction of balanced cross-sections are successfully used for the foreland areas (for large folds which have “parallel” style) [Woodward et al. 1989]. These methods are not applicable for the hinterlands (for numerous small folds which have “similar” style). Thus, if the generalized cross-section of the hinterland is based on the geological data only, the result is mostly the opinion of the authors (or the interpretation of the structure based on some theory) than an exact (numerical or balanced) reconstruction. For example, the cross-sections by Dotduev [1987] show decollements at a depth of 5-10 km and underthrusting of the TM rigid block under the GC structures. Such kind of the GC structure is the conventional model, but some geological data didn't shown the presence of the decollements [Somin, 2000].

We developed the complex of special methods for solving of this problem. We consider the structure of the hinterland as a hierarchic system of folded structures, according to the volume of the layers occupied by the object at each hierarchical level. There are at least seven levels from a specimen (the 1-st level) as an intralayer object (which is usually studied by the strain-analysis), to a single fold (the 2-nd, the layer of rock), up to the tectonic zone (the 5-th, the crust as a layer), to a meganticlinorium (the 6-th, the lithosphere) and to the folded belt as the total (the 7-th level). All the methods are kinematical one, based on the mechanical approach and on some mechanical models [Yakovlev, 2002; Hudleston & Stephansson, 1973]. The most interesting result for the discussed problem is the reconstruction of the prefolded state of the structural section across the Chiaurskaya zone (the ChZ, the southern zone of the GC). The section was divided into 26 domains (homogeneous parts of the folded structure of $\sim$ 1 km width, the 3-d level ,as a part of the sedimentary cover), and the geometric parameters (such as inclination of the axial plain, inclination of the envelope plain, the shortening value) of each domain were measured. The developed method allows us to reconstruct the prefolded state of each domain and thus, the prefolded state of the cross-section as the total was compiled. This method may be considered as a kind of the reconstruction of the balanced cross-section for the hinterland structures [Yakovlev, Voitenko, 2005]. Conventional methods of shortening measurements, based on the mechanical approach, are limited by specimens or some larger volumes of rocks only [Ramsay & Huber, 1983; Ramsay & Huber, 1987; Woodward et al. 1986]. The value of shortening of the cross-section was calculated as the ratio of the recent length (L1=28155 m) and the prefolded length (L0=62308 m), SH=L1/L0=0,452. The minimal volume of sedimentary cover, whose shortening can be calculated exactly, is a "structural cell" or the half of the anticlinorium (the 4-th level, the sedimentary cover, as total). The section was divided into four such cells, and their shortenings were estimated as 0,563; 0,419; 0,400; 0,406 from the South to the North.

The section line is passing through the stratigraphic column of the initial thickness of about 7 km from the Upper Jurassic to the Upper Cretaceous. It is known [Milanovsky & Khain,1963] that the Lower and the Middle Jurassic rocks underlay this part of the sedimentary cover of the initial thickness of about 5-6 km. We can estimate the thickness of the Paleocene and Eocene rocks (the upper part of sedimentary cover) as $\sim$ 1-2 km. Therefore, the total initial (vertical) thickness of the sedimentary cover in Chiaurskaya zone is about 13-15 km. It means that we know the initial vertical thickness ($\sim$ 14 km) of each of the four "structural cells" and their initial lengths. The square of each of these transversal sections should be constant during the folded deformation, of course. Thus, we can estimate the recent theoretical vertical thickness of each cell based on these data and on the shortening values (such as 25 km; 33 km; 35 km and 34 km). It is also possible to place these recent columns to the recent section so that the average stratigraphic level of the cells remains the same as the level into the section-line. Thus, the most common possible depth of the stratigraphic level J_1/Pz (the sedimentary cover/basement boundary) can be obtained for each cell (such as 19, 22, 25 and 16 km). If there were no erosion and additional deformation processes in the upper part of the sedimentary cover, the heights of the column tops are 6, 11, 10 and 18 km, based on the same assumptions [Yakovlev, 2006].

The Transcaucasus Massif (TM) contains the Dzirula platform block (DPB) and the Okribo-Sachkhere zone (OSZ) as the main elements in the region from the Rioni river to the Greater Liakhva river from West to the East. There is the Gagro-Djava zone (GDZ) as an additional southern part of the GC to the west of the town Djava and of the discussed cross-section. The Racha-Lechkhum fault zone (RLFZ) and the Utsera fault (UF) are the main faults in this region. The first zone has about $\sim$ 5-10 km width and consists of numerous blocks and faults. It represents the boundary between the GC (the ChZ and the GDZ) and the TM. The Utsera Fault is the boundary between the GDZ and the ChZ in the West and joints to the RLFZ in the East of the region. The main folding episodes of the DPB took place at the Late Paleozoic [Milanovsky & Khain,1963]. All younger deposits have platform types of rocks, horizontal undeformable layering and minimal thickness (about 0,8 - 2 km from Jurassic up to Paleogene). The total thickness of the cover deposits in the OSZ from J_1 to J_2 is about 3-5 km. The structure has a common dip of layering to the North, rare folds, and several faults (thrust ?) only. The Upper Jurassic and Cretaceous-Paleogene rocks are mainly para-platform limestones having horizontal layering and thickness about 1-2 km. The structure of the RLFZ stripe includes high grade shortening of folds in blocks of J_1-J_2 deposits, several large folds, and some thrusts in J_3-Pg_2 deposits. The GDZ has the similar structure, but the thickness of J_3-Pg_2 deposits varies from 500 m to 1-2 km. Local decollements and gently sloping thrusts exists near the Utsera Faults and in the RLFZ near the Chiaurskaya zone. A narrow depression strikes along the RLFZ, filled by the Neogene terrigeneous deposits. This depression looks like of a ramp graben, and has folded layering at the East of the region. Local faults (kinematically thrusts) of the RLFZ to the East of the Utsera Fault have inclination of about 60-70 degrees to the North. The Upper Cretaceous sediments are existing in the northern hanging wall and the Bajossian volcanic rocks are existing in the southern footwall (as total situation) in the southern portion of the cross-section.

The description of structure and stratigraphy of the two main neighboring blocks (such as, the GC and the TM) and estimates of shortening of the ChZ blocks are enough for the reconstruction of the deep structure of the RLFZ and for the reconstruction of the main historic events. Probably, the ChZ was sank more than the OSZ and the RLFZ has acquired the normal fault magnitude near 1-2 km during the J_1-J_2 period. The folding of J_2/J_3 episode took place in the OSZ and the GDZ only. The ChZ has sank much more intensive than that of the OSZ and the GDZ during the J_3-Pg_2 period. The normal fault magnitude of RLFZ increased up to 8-10 km for the J_1/Pz stratigraphic level boundary. The main folding of the GC at the Pg_2/Pg_3 time produced shortening about 0,5 for the ChZ. As detected from the first conglomerates appearance [Milanovsky & Khain,1963], mountain building was started much later, at the Sarmat time (Later N_1). It means, according the special calculations (as described above), that the normal fault magnitude of the RLFZ increased up to 16-20 km for the J_1/Pz stratigraphic level boundary. At the same time, the upper part of the ChZ sedimentary cover was thrusting kinematically over the OSZ and the GDZ blocks with some vertical magnitude. Some blocks of the OSZ and the GDZ have the upper position and lower ones along the UF and the RLFZ. The Lower Cretaceous rocks of the ChZ were thrusted on the J_2-J_3 rocks for the first cases (formal normal fault). The second cases are the thrusting of the Lower Cretaceous rocks over the Pg_3-N rocks and they are true thrusts. These thrusts are considered as local structures only, which are some complications of more common structure of RLFZ. The common structure of the RLFZ as transitional zone from the GC to the TM is a large magnitude normal fault. During the mountain building stage, the magnitude of the normal fault decreased down to 12-16 km) due to the uprising of the GC.

Thus, the ChZ has had the considerable sinking since J_3, which was completed at the end of the Eocene. The basin inversion at Pg_2/Pg_3may be considered as the partial one, which has appeared due to folding process into the ChZ. Their main properties are the abrupt sinking of the “sedimentary cover/metamorphic basement” stratigraphic boundary and (at the same time) the uprising of bottom of sea and, possible, the appearance of small relief. During the Maikop time (Pg_3-N_1), the sedimentation has started again, in places, on the eroded surfaces. The last basin inversion since the Sarmat time has other nature, because strictly mountain building is taking place without the noticeable shortening, and the “sedimentary cover/metamorphic basement” stratigraphic boundary is uprising also.

This result contradicts to the conventional models of the kind of subduction of the TM blocks under the GC (similar to [Dotduyev, 1987]). The models like the Dotduev’s cross-section use only a small part of numerous structural data on folded structure and faults of the GC. Thus, it is mostly the interpretation than the reconstruction. Also, such models are never the balanced cross-sections. The typical error is transferring of a well-known foreland type of structure to an unknown hinterland area without special studying. For instance, the hinterland hasn’t a rigid basement (but it is true for a foreland, of course) and this is one of the reasons not to use such transferring.

The main problem for the proposed model of the RLFZ deep structure is a simultaneous existence of normal faults and thrusts. To explain these structures, it is useful to introduce the conception of a new kind of the fault which joints a rigid block and a deformable block. This fault is large (more than several kilometers vertical magnitude) and this is the reason that such kind of structure is not well-known. The deformable block consists of folded layers, and its initial vertical thickness increases. This means that the magnitudes of displacements are different for different places. Some (neutral) level can have no relative displacement. The upper part of the block from this level of the sedimentary cover will upraise, whereas the lower part will sink down. The magnitude of the displacement at any lever will increase, according to the distance of this level from the neutral level. In the common case, it will be thrusting of the upper part of sedimentary cover and normal faulting of the lower part. The next part of problem is the determination of stress regime (geodynamic model) for GC in frame of the proposed model. The conventional models have the thrusts only during the folding and the compression from neighbour blocks (TM on the South and Scythian plate on the North) is satisfactory model. The increasing of normal fault (according to the proposed model) contradict to this idea. We are offering not to push only for the appearance of shortening of structure, but to pull down the common bottom of GC as a part of stress regime. This idea is explaining the local thrusts and total normal fault simultaneous existence, the subsidence during the Maykop time and the downward movement of bottom of GC structure during the shortening due to folding. It is difficult to explain these three geological facts in frame of conventional models which have compression from neighbour blocks only.

Conclusions

The special detailed study of the transitional structure from the Great Caucasus to the Transcaucasus Massif based on the estimation of fold and fault related deformations has shown that the structure of the hinterland can be reconstructed to the depth of 10-30 km. The conventional model of the collision structure of the Great Caucasus based on the subductional model or on the usual foreland type of the detachments should be used with great caution, because the properties of real local structures (thrusts) can be erroneously transferring to the common structure, which can possess quite different properties (such as a large scale normal fault).

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