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Description of linear folding deformation on base of parameters of strain ellipsoid for the fold formation mechanisms detection: examples from different scale structures of Greater Caucasus

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The problem of definition of the formation mechanism of structure is the basic for tectonophysics. For this purpose tectonophysics involves methods of mechanics and physics. The well-known and approved approaches of continuum mechanics, based on studying of stress fields, are usually used. This direction is successfully applied to research of modern structures based on earthquake mechanisms or to study of ancient structure using shear features. These two kind of objects should have small deformations.

The study of stress fields into structures with the large deformations isn't quite correct for purpose of detection of its formation mechanisms. Speculative theoretical models are used for explanation of formation mechanisms of folded structures usually. In these cases the most general structure of natural object receives the interpretative model. Meanwhile there are possibilities to give the description of deformations in theoretical or experimental model on a basis of strain ellipsoid, to reveal the general and various features of development of different models and to compare natural structures with theoretical ones. On this way first two purposes exist: 1) a separating all objects to some hierarchical levels and 2) elaborating of methods of deformation parameters definition (shortening value mainly) for them.

The new direction of researches named "multirank strain analysis" (Yakovlev, 2008a) is offered. There are seven hierarchic levels of folded objects for which the certain volume of layering and certain kinematic models of their formation is characteristic. There are: intralayer deformations, folds (layer), domains (a pack of layers), structural cells (whole sedimentary cover), tectonic zones (all crust), folded systems (such as Greater Caucasus; lithosphere as a layer?) and a folded belt entirely. In the given work, concepts about folds and folded domains for the analysis of formation of local structures and of tectonic zones are used.

Two methods of definition of shortening value in a direction perpendicularly to an axial plane are offered based on the form of a competent layer in a fold. The first method concerns sinusoidal folds of an individual viscous layer in less viscous medium. Measurements of the form of a layer in the model of such structure (Hudleston, Stephansson, 1973) were made. There are parameters: the angle between limbs of folds and the relation of length of a limbs and thickness of a layer (Yakovlev, 1978, 2007, 2008b). Based on these parameters, the diagram was constructed which is connecting these values (on axes) with a shortening value of folds and contrast of viscosity a layer/medium (net of two isolines). Measurements of the form of a layer of natural folds allows to define these two goal-parameters using this diagram. The second method concerns folds of "similar" morphology type in alternation of a competent/incompetent layer . Offered kinematic computing model is using superposition of mechanisms of a buckling and flattening, which are repeating in numerous iterations. The nomogram was constructed based on this model. Inclination of a fold flank concerning an axial plane and the relation of thickness flank/hinge are the axes of this nomogram. Shortening values and a parity of mechanisms are set of isolines which were placed after calculation. It is possible to define these two goal-parameters, placing the measurement of natural fold geometry on this nomogram (Yakovlev, 2002, 2007, 2008b). Researches of natural folds of these two types (78 and 36) in the Chiaur zone of the Greater Caucasus have shown high convergence of results for local structures that speaks about good reliability of these methods.

Strain ellipsoid is inscribed in a linear cylindrical fold of "similar" type of morphology definitely: the lengthening axis is parallel to a fold axial plane, the intermediate axis is parallel to a hinge line (deformation in this direction is small or zero), the shortening axis is perpendicular to an axial plane. The first parameter of ellipsoid is related to a shortening axis; this is a shortening value (SH). Orientation of an axial plane (AX) gives, accordingly, the orientation of ellipsoid in space. The third parameter is added to these two parameters for the folded domain; this is an orientation of an envelope plain of folds (EN).

The method of definition of shortening value for multilayers folds has been used for detection of the mechanism of formation of local structure – the Vorontsovsky nappe on southern border of hinterland of North-West Caucasus near town Sochi. Numerous folds have been studied in a frontal part of 15-km of a body of the nappe in the

tunnel which passed through a zone of detachment. Two possible geodynamic mechanisms have been theoretically investigated: 1) lateral shortening as a result of pressure from the Greater Caucasus due to underthrusting and 2) horizontal simple shearing due to gravitational sliding. Two trends of change of parameters of an ellipsoid (ellipse for linear folds) have been received: AX and SH which strongly differed each other by final value of axial surfaces inclination at high value of shortening: vertical for the first model and horizontal for second one. Results of measuring of 39 folds of natural structure have been placed on diagram AX/SH. Cloud of points was compared with theoretical models. It has been shown that the cloud of natural folds points corresponds to a trend of the horizontal simple shearing and it corresponds to geodynamic situation of gravitational sliding.

Experimental models of three authors have been studied that has allowed to study trends of change of parameters AX, SH, EN for development of several mechanisms. These trends used specific paths of parameters changes which go out from a starting point, where AX=90 (vertically), EN=0 (horizontally), SH=1.0 (shortening SH=l1/l0 is absent). The three-dimensional space of signs AX – SH – EN was studied on three diagrams AX/SH, EN/SH, AX/EN. Experimental models of lateral pressure (accretionary prisms) of Dixon (Dixon, Tirrul 1991, Dixon, 2004) and of Guterman (1987) have been studied. It has been defined that simple lateral shortening doesn't change parameters AX (nearby 90) and EN (nearby 0), only SH increases. Mechanism of a horizontal shearing take place at a friction concerning the base of model. Orientation of axial surface AX changes (130-150º against 80-110º) and the value of shortening SH increases (0.3-0.5 against 0.5-0.6) concerning the first mechanism. Models of gravitational sliding by Guterman (1987) in its zone of compression were similar to model of lateral pressure and horizontal shearing. Domains of local mechanism "near thrust" have been found in this model of lateral pressure. At its action the orientation of an axial surface changed to 130-150º, the difference of angles AX - EN increased and the shortening value increased also. All these models didn't create structures which have large bends on the scale of a sedimentary layer. Models of diapirism of Goncharov (1979) have shown large bends (mesobending) in scale of whole layering of model. But experimental and theoretical models of diapirism have shown also weak shortening in domains regarding natural folds. On the basis of mathematical model of advection of Goncharov (1979), the model of mesobuckling is offered in which the diapirism was combined with the shortening (Yakovlev, 2003).

Structural sections of three zones of the Greater Caucasus, which are covering its basic part, have been used for comparison with experimental models. These are three sections in the most southern Chiaur zone (the Central sector of Caucasus), the in which flysch carbonate deposits of Upper Jurassic, Cretaceous and of Paleocene are crumpled in folds (Yakovlev, 1997, 2001). Next structure to the north from Chiaur zone is Tfan zone in South-East sector of the Greater Caucasus. Seven sections have been studied here, in which flysch-like terrigenous rocks of Middle Jurassic and carbonate flysch deposits of Upper Jurassic are deformed in numerous folds. To the north from Tfan zone, the structure of the Shakhdag zone in the same sector has been studied in 2 profiles. Flysch-like terrigenous rocks of Low and Middle Jurassic are crumpled in folds here. All 12 profiles have been divided into domains by total number 151. Three sets of domain geometry measurements were placed as points on diagnostic diagrams AX/SH, EN/SH, AX/EN. Areas of these sets have shown strong similarity of morphology of all three zones on configurations of the most developed domains that speaks about their genetic affinity. Values of parameters reached next quantities: 80-100º AX, 0.2 SH on the first diagram; -70º EN, 0.2 SH, also as 70º EN, 0.3 SH on the second one; cloud with mesobuckling properties occupied space from 70º AX,-70z EN up to120º AX, 70º EN. Three zones differed from each other: 1) on areas of points in rear parts, which is closer to a starting point, and 2) in a direction of vergence of "near thrust" domains. It has been defined that the folding of Chiaur zone is most developed, southern vergence of structures is observed here. The Tfan zone has average development and both vergences. The Shakhdag zone is least developed, northern vergence is observed here (Yakovlev, 1997, 2001).

Areas of points of natural folding on diagnostic diagrams AX/SH, EN/SH, AX/EN were compared with areas of the studied reference mechanisms. It is shown that the combination of synthetic model or mesobuckling (it is aggregation of diapirism and shortenings) and the "near-thrust" mechanism of formation of local structures as a first approximation explains occurrence of their existing morphology at semi-quantitative level. Structure domination of an accretionary prism or lateral pressure, also and pure diapirism doesn't prove to be true (Yakovlev, 1997, 2001).

A number of additional researches has shown existence of a considerable swing of a surface of "sedimentary cover/basement" boundary with differences of depths up to 20 km, and also the same shortening of a cover and the basement (Yakovlev, 2008c, 2009). Being based on it, and also on the results of study of existed experiments specified above, it is possible to specify in necessity of elaboration of new techniques of experiments on reproduction of folded structures. Such experiments should provide the occurrence of large bends and vertical movements of blocks of the basement.

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