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GEOPHYSICS

A New Kinematic Model of Strike-Slip Faults

A. I. Timurziev

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The traditional views on the compression or extension regime with a shear component dominant in the Earth's crust are usually opposed to each other, being considered in the context of different geodynamic structure formation settings. The classification of transpression and transtension regimes that determine the formation of strike-slip faults [6] represents the most illustrative example of such an approach.

This communication demonstrates the inconsistency of kinematics of transpression and transtension "flower models" with real 3D models available for strike-slip fault zones [1]. The study of shear zones based on interpretation of 3D seismic exploration data in different-age sedimentary basins of the Earth reveals their formation under conditions of pure shear with simultaneous compression and extension in mutually orthogonal sections. The comparative analysis reveals that transpression and transtension models are less useful than 3D models illustrating the geological structure of sedimentary basins. Consequently, recent views on the mode of crust deformation and structural parageneses of shear zones reflecting past concepts of flat (two-dimensional) geological thinking are incomplete and need to be revised.

The main thesis postulated in this work is the assertion of the simultaneous action of the volumetric irregularly strained state reflected in three main types of geological medium deformations (compression–extension–shear) in mutually orthogonal sections of crustal structures during their formation.

STRUCTURAL PARAGENESES OF STRIKE-SLIP FAULT ZONES BASED ON MODELING

The traditional concepts of destruction structures reflecting the mechanism of horizontal shear are based on models proposed by W. Riedel (1929) and E. Anderson (1951). According to Riedel's model, the strike-slip zones comprise en echelon located *R* and *R*' shears oriented almost orthogonally to the strike-slip fault axis; detachment cracks; *T*, *P*, and *L* shears; and en echelon arranged fault-line plicative folds *F* with elongated axes parallel to the maximal extension axis. The experimental study of deformations in shear zones with physical modeling shows that the strike-slip fault formation represents a chain of discrete deformation events for spatially isolated structural parageneses. Surface structural parageneses of shear zones are well studied, which is far from being true of volumetric deformations, since methods of physical modeling provide no such opportunity.

These model concepts are used for interpreting natural structural parageneses in alternating transpression and transtension geodynamic settings. The data on structural parageneses of shear zones are summarized in [3], where the author discusses, following [5, 6], the main types of deformations for kinematic transpression and transtension settings.

The results of physical modeling performed together with scientists from the Laboratory of Tectonophysics and Geotectonics (Geological Department, Moscow State University) [2] explain the formation of shear deformations characteristic of the overburden of West Siberia [1] by a combination of two types of horizontal displacements: along the vertical and horizontal planes without the contribution of transpression or transtension.

KINEMATIC INCONSISTENCIES OF "FLOWER STRUCTURES"

The study of surface displacements related to strong earthquakes in New Zealand, Japan, and California resulted in development of the doctrine of faults with displacements along their strike (strike-slip faults) [6]. Transformation of the Wegener's concept of the continental drift into the mobilistic theory owed much to the doctrine of transform faults [7], which substantiated the possibility of large-scale movements of lithospheric plates. The classification of strike-slip faults [8] as well as their geometric, kinematic, and dynamic characteristics was developed based on the study of horizontal displacements in fold belts. As is noted in [6], many concepts and problems concerning strike-slip faults originate from the study of the San Andreas Fault.

The main constraint on the results of these studies consists in the fact that the eroded sections that were examined demonstrated only fragments of two-

Central Geophysical Expedition, Moscow, Russia
e-mail: aitimurziev@cge.ru

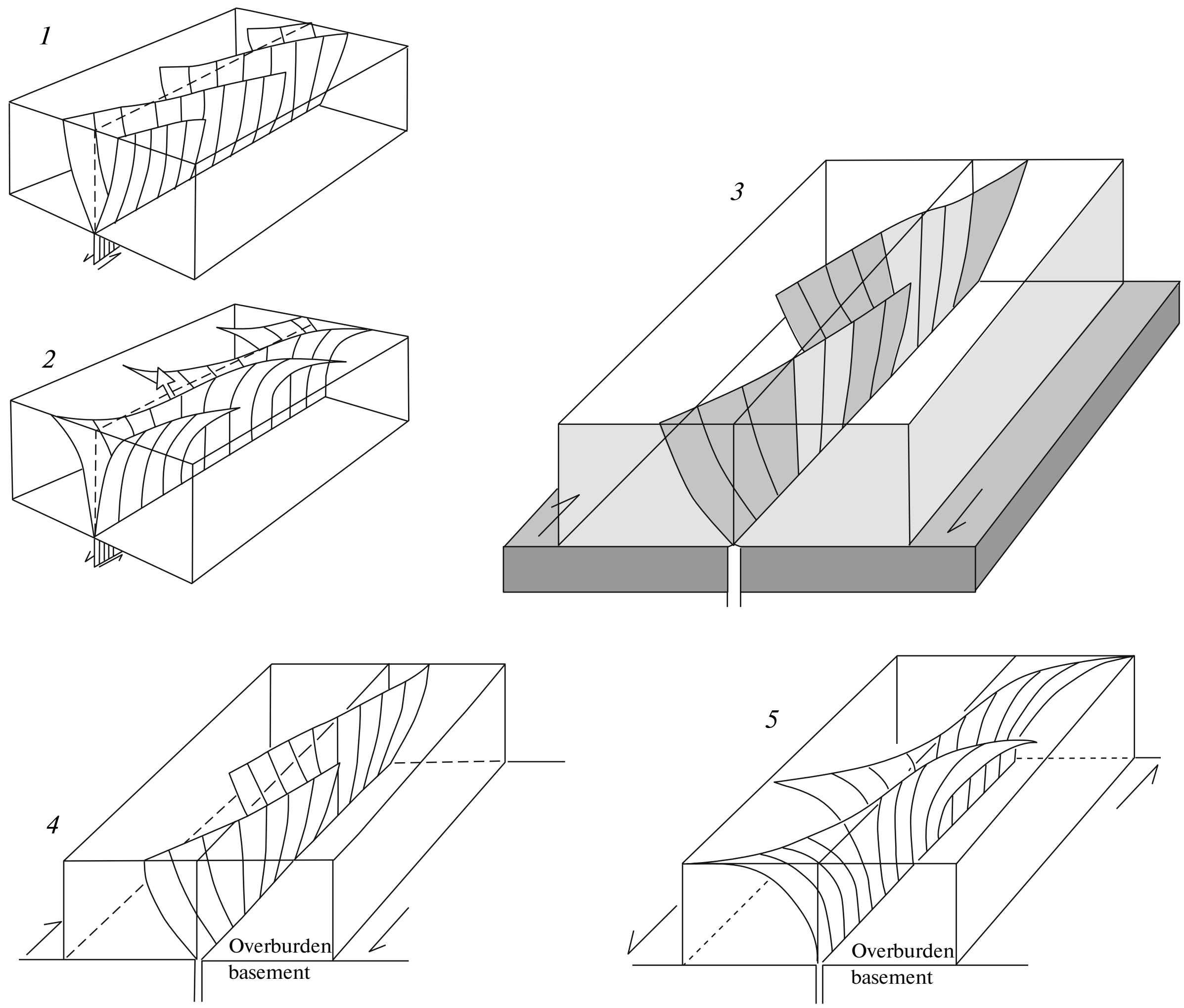

Fig. 1. The kinematic model of "flower structures." (*1*) "Tulip" structure, left-lateral transpression (A. Sylvester, 1988); (*2*) "palm-tree" structure, left-lateral transtension (A. Sylvester, 1988); (*3*) "tulip" structure, right-lateral transpression (K. Kwolek, 2004); (*4*) helical form of individual Riedel shears in a simple right-lateral strike-slip fault; reconstructed using horizontal sections of experimental sand models (Naylor et al., 1986); (*5*) helical form of axial surfaces of two en echelon folds in a simple left-lateral strike-slip fault (Naylor et al., 1986).

dimensional structural parageneses of shear zones. These early models of strike-slip faults could not take into account all the complex interactions between fold–fracture structures in their volumetric relationships. In this connection, Sylvester [6] formulated several basic aspects, i.e., the formation mechanism of en echelon folds and their relation with the strike-slip fault formation included, which remain recondite thus far.

Thorough analysis of "flower structure" models [5, 6, and others] reveals their distinct inconsistencies with kinematic conditions of natural strike-slip fault zones as well as with models of other authors or models proposed by the same authors in different years. Below are the most evident discrepancies ("kinematic rebuses") among graphic illustrations of "flower structures" available for the strike-slip fault zones (Fig. 1) in [5, 6]:

(1) incorrect kinematics of strike-slip faults (in Figs 1.*1*, 1.*2*, 1.*5*, right-lateral strike-slip faults are shown as left-lateral, while in Fig. 1.*4* their kinematics is right-lateral);

(2) plains of lobes of echelon structures cross the strike-slip fault axis as continuous bodies forming helical fault planes lacking its axial rapture (in natural conditions, en echelon elements of one of the structure limbs do not cross the axial surface and do not pass into the neighboring block);

(3) under movement of opposite blocks toward each other, en echelon elements slide along the rapture plane (like along railing) curling, not rupturing, and shifting relative to each other;

(4) the dip angles for the individual en echelon element vary from zero (relative to the vertical plane) in its middle (intersection with the strike-slip fault axis) to maximal values at its end (in natural conditions, a zero dip angle the of en echelon plane corresponds to

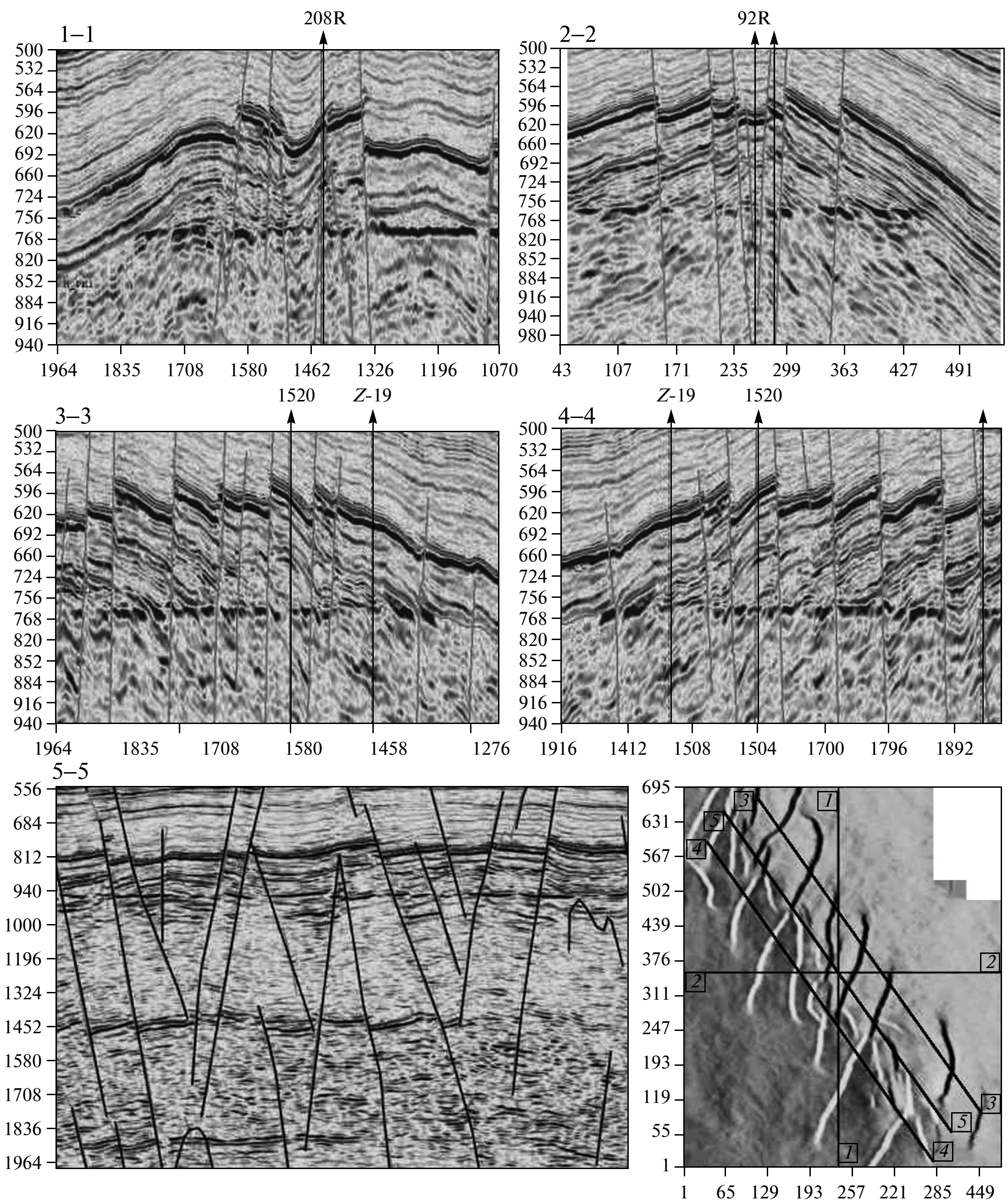

Fig. 2. The kinematic model of the horizontal offset structure.

the line of en echelon pinching out above the vertical projection of the strike-slip fault plane);

(5) "flower models" are lacking signs of en echelon pinching out in the suture zone of the strike-slip fault;

(6) the inconsistency between kinematics in models proposed by Sylvester (left-lateral strike-slip fault) and Kwolek (right-lateral strike-slip fault) against the background of their morphological identity;

(7) the occurrence of antiforms and synforms within the transtension and transpression "flowers," respectively, while "flower structures" are characterized by opposite relationships.

The discrepancies detected in Riedel's model concern also structural parageneses of natural shear zones and their relationships. This is true of obscure Riedel shears (*R* and *R*') and *P* and *L* shears, as well as discordant orientation of en echelon folds *F* relative to the strike of the maximal compression axis. Dissimilar to Riedel's model, the strike of fault-line plicative folds in natural conditions is orthogonal to the vector of maximal tangential stresses τ_{max}. Other discrepancies are discussed below.

A NEW KINEMATIC MODEL OF STRIKE-SLIP FAULTS

The horizontal offset structure, which represents the main structural object for this study, shows morphological similarity with "flower structures." Nevertheless, this term is more capacious with respect to both form and content [1]. The comparative analysis leads to the conclusion that the statement of question as to whether the structure was formed under transpression or transtension conditions is incorrect: kinematic shear zone parageneses of the "tulip" and "palm tree" types exist only together. In well-developed structures formed by strike-slip faults in the basement, different sections of the basin overburden record both structural parageneses and reflections of different regimes: compression, extension, and shear conditions. The manifestation degree of these kinematic conditions is determined by the selected observation section, relative deformation of the structure against the background of the regional deformation field, and scale and type of observations (two- or three-dimensional).

These inferences are supported by factual material. Figure 2 demonstrates the proposed kinematic model of the horizontal offset structure. It shows real 3D seismic profiles across the Ety–Pur Swell (West Siberia) in five critical sections reflecting different styles of deformations and simultaneous manifestation of all the known structural–kinematic parageneses of the horizontal offset structure. The positions of sections in the latter are shown in the map of dip angles that characterizes the structure of the en echelon zone of faults feathering the horizontal basement displacement, which are developed in the Upper Jurassic Bazhenovo Formation (the area is 11 × 17 km in size). Section 1–1 reflects the meridional compression regime dominant in the structure arch (axis σ_{max}), section 2–2 corresponds to latitudinal extension (axis σ_{min}), and sections 3–3 and 4–4 reflect the horizontal offset (axis τ_{max}) observed at different limbs of the fold. Section 5–5 characterizes alternating compression (horsts) and extension (grabens) regimes in the strike-slip fault suture zone. Sections 3–3 and 4–4 demonstrate simultaneous interstratal shifts (horizontal displacement in the horizontal plane) resulting in plastic rock pumping and section doubling [1].

A peculiar feature of the horizontal offset structure is development of normal faults in the uplift arch (section 2–2), while positive "flower structures" (Positive Palm Tree, Transpression) are formed on reverse faults. To the contrary, section 1–1 demonstrates development of reverse faults against the background of the local trough, while negative "flower structures" (Negative Tulip Structure, Transpression) are formed on normal faults. Both types of "flower structures" (transpression and transtension) are characterized by divergence of feathering faults toward the basement and upward opening of "flowers." For the horizontal offset structure, compression (1–1) and extension (2–2) sections are characterized by opposite directions of fault divergence: downward "flower" opening in the first case ("wedge" is oriented upward) and upward "flower" opening in the second one ("wedge" is oriented downward). The important feature of the horizontal offset structure is the development of antiforms within the graben (trough) on the uplift arch (2–2) and synforms within horst (uplifts) (1–1), contrary to sign-opposite forms in "flower structure" models (Pull Apart Basins and Push Up Ridges). In the horizontal offset structure, rock movements inside the "wedge," which determines the kinematics of faults, is directed toward its narrow end; in "flower structure" models, such a situation is characteristic only of the transtension regime.

The above-mentioned inconsistencies in kinematics of shear zones indicate that the "flower" models should be revised. The study of horizontal offset structures based on 3D seismic exploration data shows that they were forming in pure shear conditions under the simultaneous influence of compression and extension in mutually orthogonal sections. The transpression and transtension models are inadequate compared to the 3D structural models of natural geological objects in sedimentary basins. The significance of this inference is determined by the fact that unconditional acceptance of kinematic transpression and transtension models became practically universal and they are used for explaining regularities in the formation of different structures: fold belts, cratons, rifts, and fold–thrust structures of the crust [3–8]. This doctrine is widely used also for explaining the structure and formation of sedimentary basins [4–6]. This reflects a tendency for simplification of structure formation and reduction of diverse geotectonic settings to geomechanical transpression and transtension models as single and universal structure-formation mechanisms.

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