ISSN 0145-8752, Moscow University Geology Bulletin, 2016, Vol. 71, No. 4, pp. 290–295. © Allerton Press, Inc., 2016.
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Structural Paragenesises of the Flysch Complexes in the Central Part of the Uralian Foredeep

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Received December 8, 2015

Abstract—The structural features of the Upper Paleozoic flysch formations in the central part of the Cis-Uralian Foredeep were studied. Three types of structural paragenesises typical of thrust zones were distinguished. Among them are west vergent inclined folds and overfolds that pass into recumbent folds near a fault plane, structured tectonic melange, local thrusts, schistosity zones, and flat slipping planes. The various structural elements extend from northwest to northeast, due to the structural heterogeneity of the allochthon, approximately parallel to the strike of the Karantrav thrust.

Keywords: Urals, Uralian Foredeep, flysch, structural paragenesises, fold, thrust, vergency

DOI: 10.3103/S0145875216040062

INTRODUCTION

The Uralian Foredeep consists of several troughs separated by sedimentary basins (Fig. 1). The Ufimian amphitheatre is among its structural elements; this is an arched uplift with an east-oriented convex, which is located in the southern part of the Yuryuzan–Sylva depression and corresponds to the approximate boundary between the Southern and Middle Urals (Mizens, 1997; Puchkov, 2010). The Yuryuzan–Sylva depression is separated from the Belskaya Depression by the Karatau uplift, which is regarded as a horst (Kisin, 2008) or a large allochthon (Shakurov, 2014). The southernmost part of the Yuryuzan–Sylva depression is usually called the Sim trough, which is a structure of a higher order. The photos in this article were made by the authors.

The Ufimian amphitheater is composed of Middle Carboniferous (Moscovian Stage) to Lower Permian (Artinskian) formations; the upper part of the sequence is denuded. In general, the sequence of the Ufimian amphitheatre is quite facially diverse: alternation of thick flysch sequences, conglomerate units (from boulder to pebble), and olistostrome horizons. The volume of olistoliths of Lower Carboniferous limestones is up to several thousand cubic meters. At some levels the flysch is separated by limestone beds. To the west of the Ufimian amphitheater the flysch becomes more common. The sequence of the Sim trough is characterized by almost universal development of fine-grained facies types.

The rocks of the Uralian Foredeep are folded into large submeridional small-amplitude folds (100–200 m). This regional structure is highly asymmetric and is characterized by a distinct western vergence, which is determined by the inclination of common axial planes of inclined and overturned (to recumbent) folds and the majority of fault zones (predominantly, reverse faults and thrusts), often with significant strike-slip component. In general, we have studied the Karantrav thrust: the main thrust fault determines the structure of the Ufimian amphitheatre. The main thrusts of the Yuryuzan–Sylva depression are Mesyagulovo, Yukalikulevo, and Karantrav. During our work we studied the main Karantrav thrust, which, as a whole, determines the structure of the Ufimian amphitheater.

Most of the thrust fault structures in the Uralian Foredeep were identified and explored as a result of drilling works (Kamaletdinov, 1974; Kazantsev et al., 1999; etc.). It should be noted that structural paragenesises of thrust zones (and some other fault zones) are still poorly studied. They provide the maximum amount of information about the nature of faults and their kinematics.

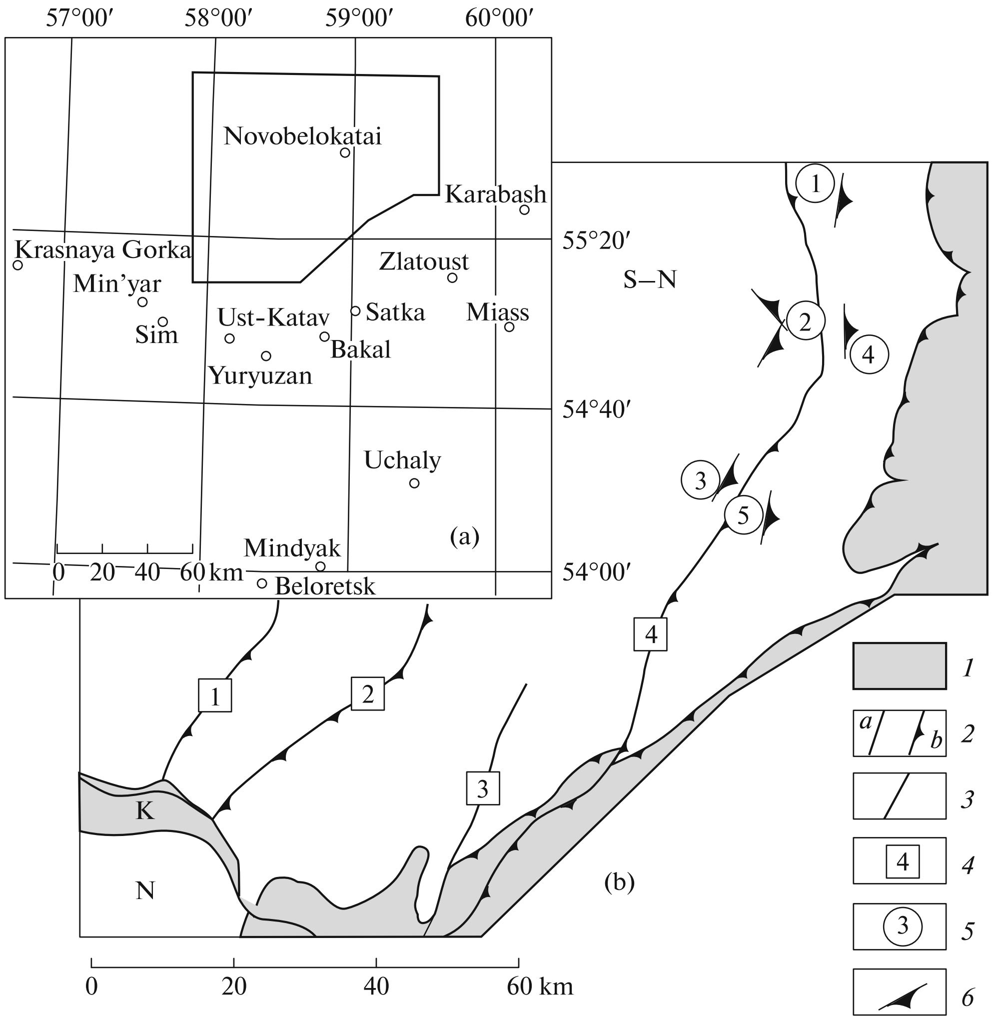

Fig. 1. A schematic location map of the study area (a) and the objects of study (b): *1*, complexes formed before the Moscovian Stage of Middle Carboniferous; *2*, faults: (*a*) of unknown kinematics, (*b*) thrusts; *3*, stratigraphic boundaries; *4*, numbers of faults; *5*, numbers of objects of study; *6*, dip directions of axial fold planes, faults, foliation, etc. The numbers in squares are faults: 1, Mesyagulovo; 2, Yukalikulevo; 3, Lakly; 4, Karantrav. The numbers in the circles are objects of study: 1, Kurga; 2, Kalinovka; 3, Urakovka; 4, Unkurda; 5, Karantrav. The letters in the scheme: U–S, Yuryuzan–Sylva depression; K, Karatau ridge; S, Sim trough.

Statement of the task. Since many structural elements form sustainable combinations in different locations at varying scales, the study of these elements within fold regions gave geologists the idea that apart from the genetic link there is a paragenetic link between them. The term "structural paragenesis" (natural combination of various structural elements) has many definitions, which can be categorized into three main types:

—*dynamic*, in the case of a uniform stress field;

—*kinematic*, when the development of major structures is under consideration;

—*deformational*, which defines a unified mechanical environment.

From our point of view, it is most reasonable to interpret tectonic structures in terms of deformation processes. This makes it possible to identify structural paragenesises that combine deformation structures manifested under conditions of unified mechanical environments: compression, extension, a strike-slip fault, transpression, transtension, and flow (Kirmasov, 2011).

Formation of all of the basic structural components of the unified paragenesis suggests the existence of a common mechanism of their development. In other words, the development and geometry of structural elements grouped into a "structural paragenesis" must be satisfactorily explained by a theoretical model. If we remove the theoretical component from the definition then it will be possible to group any structural elements that are located approximately in the same environment into a "structural paragenesis." However, this is contrary to the meaning of the above idea. Structural paragenesises can comprise different scale elements: macro-scale (fold zones), mesoscale (single folds, boudinage structures, slip planes, etc.), and even microscale (kink bands in thin sections, wavy cleavage, etc.).

The aim of this work was to establish structural paragenesises in the southern part of the Yuryuzan–Sylva depression within the Ufimian amphitheater; the main objectives were to identify the different-scale structural elements and reveal the deformation environments of their development.

Data and materials were collected during additional site exploration (preparation of the 1 : 200000 State Geological Map for the publication) of a wide band of eastern outcrops of Upper Paleozoic formations within the Ufimian amphitheater in the Belokatai District (from the latitude of the town of Nyazepetrovsk in the northeast to the village of Akhunovo in the southwest). Structural paragenesises were studied in natural outcrops and quarries for building stone excavation and roadway excavations. The objects of study were selected so as to more fully characterize the structural elements of various scales, whose formation was associated with the development of fault zones.

Particular attention was paid to the Karantrav fault zone (Fig. 1, no. 4), which is a thrust fault that sometimes passes into the overthrust fault. The Upper Paleozoic formations in the thrust zone (both in autochthon and allochthon) are intensively dislocated. Within the allochthon, rocks of different formations, which, as a rule, have vertical bedding and sometimes have overturned bedding correspond to steep limbs of local inclined and overturned west vergent folds. Several studied objects will be discussed in detail below (the numbers in parentheses correspond to the numbers in the circles in Fig. 1).

The Kurga object (1). In the 1.5 km eastward of the village of Kurga (a hanging limb of the Karantrav fault near its northern segment) the contact between layered limestones of the Lower Permian Akhunovo Formation and overlying flysch deposits of the Sharipovo Formation is uncovered in a quarry. The bedding of the limestone beds is vertical (Fig. 2); in the contact zone limestones dip at an angle of approximately 80° to the east beneath the Sharipovo Formation (overturned bedding). To the east, they have a steep western dip (dip azimuth, 280°, ~80°). At the same time, 1.5 km westward of the village of Kurga the contact zone between deposits of the Akhunovo Formation and underlying Chigishan Formation (Upper Carboniferous–Lower Permian), is presented by sandy limestones that alternate with siltstones and mudstones. The thickness of carbonate beds increases up the section. Clastic rocks in the section disappear gradually, and, as a result, the section comprises only the strata of gray pelitomorphic limestones, which are attributed to the Akhunovo Formation. Rocks are flat-lying (<10°) and the dip azimuth is irregular. At times the deposits are contorted into wide asymmetric folds of a few meters high (Fig. 3) with steep western limbs. The hinges of the identified anticlines are gently plunging (15°) to the north (Fig. 3).

Fig. 2. Limestones of the Lower Permian Akhunovo Formation (1.5 km eastward of the village of Kurga) with near vertical and sometimes overturned bedding. This is probably a limb of an overturned fold.

Fig. 3. Limestones of the Lower Permian Akhunovo Formation (1.5 km eastward of the village of Kurga). The periclinal closure of the anticline is asymmetrical with a steep western limb and flat-lying eastern limb.

The Kalinovka object (2). A number of complex structures in the autochthon of the Karantrav thrust are uncovered in a quarry near the village of Kalinovka. The southern wall of the quarry shows an overturned anticline and conjugated west vergent syncline, which are also composed of flysch deposits of the Chigishan Formation (Fig. 4). The east limb of the anticline and the west limb of the syncline (nearly flat-lying) are gently dipping to the east; the close limb (overturned) is steeply dipping (~70°). The anticline has a sharp hinge; some of the most competent beds (sandstones among siltstones) are broken. The hinge

Fig. 4. A photo of associated overturned folds in the flysch deposits of the Chigishan Formation (village of Kalinovka, the southern wall of the quarry). Axial fold planes are shown by dotted lines.

Fig. 5. The textural features of the flysch deposits of the Chigishan Formation (village of Kalinovka, the eastern wall of the quarry). Dotted lines show marker horizons of recumbent folds; a dashed line shows a fault plane.

Fig. 6. The textural features of the wild flysch of the Chigishan Formation (the northern wall of the quarry, 2 km northward of the village of Kalinovka). Marker horizons of isoclinal folds are shown by dotted lines; dashed lines show local fault planes.

of the syncline is rounded. This structure is a combination of chevron folds and bending folds.

On the eastern wall of the quarry, the complex structure of flysch deposits is represented largely by argillites and siltstones with thin partings of sandstone, mostly fine-grained. Visually, the structure is divided into three sections (Fig. 5):

1. The upper unit (a thrust plate) is presented by the normal sequence of flat-lying almost horizontal deposits. At the bottom the unit is composed of intensively dislocated, fine-grained siltstones that consist of single limestone boudins of 40 × 7 cm in size. In the northern part of the unit boudins are arranged horizontally; in the southern part they are rotated vertically, conformable to thrust-related folded beds.

2. The middle unit (a fault plane zone) is a ~40 cm zone of intensively schistose deposits. Schistosity has a predominantly gentle dip (30°) to the northeast (the dip azimuth is 50°); sometimes up to 45°–50°. In some places, schistosity is folded into small drag folds with gentle axial planes.

3. The lower unit (an autochthon plate) is similar in rock composition to the upper one. Deposits of this unit are folded into fairly large recumbent folds. The upper limbs are sheared by a fault plane; the hinges are complicated by a series of small disharmonic folds.

The flysch complexes in the autochthon of the Karantrav thrust are more dislocated, probably due to their deformation by the allochthonous plate overthrusted from the east. Thus, the wild flysch of the Chigishan Formation is uncovered in a quarry 2 km northward of the village of Kalinovka. These flysch deposits are highly dislocated, sometimes transformed into a tectonic melange. The melange matrix is presented by abraded siltstones of the Chigishan flysch and sandstones, which occur as fragments of specific beds and folds. The tectonic melange is distinctly structured and demonstrates the common signs of a thrust-related zone. In general, all of the fragments of mesoscale folds are isoclinal closures of synforms and antiforms of western vergence and sometimes are shifted by local disruptions (Fig. 6). The beds and, accordingly, fold axial planes gently dip to the southeast (a dip azimuth is 120°–150°) at an angle of predominantly 20°–30°. In dependence on the thickness of sandstone beds, the fold hinges are rounded (thick beds) or sharp (thin beds). Local fault planes have a wavy surface and a nearly horizontal dip. At separate levels, sandstone beds are broken into small fragments and rotated. Due to this, it is hardly possible to restore their primary structure even approximately. The schistosity in siltstones of the matrix is plunging to the east with the same orientation.

The Urakovka object (*3*). Away from the Karantrav thrust, the Chigishan flysch is folded less intensively, although some elements of the structure inherit the general asymmetric structure of west vergent folds. At 2 km southeast of the village of Urakovka, two anticlines and an adjacent syncline with a western vergence, whose upper parts are cut by a local thrust gently dipping to the east, are uncovered in a road excavation (Fig. 7). Axial fold planes are curved, becoming gentler near the surface. The eastern anticline is round hinged with the southeastern limb complicated by a gentle fault, plunging (~20°) to the southeast. The northwestern limb is also sheared by a low-amplitude thrust; as a result, the entire unit is flat lying. The syncline has a carinate hinge and an almost horizontal northwestern limb. The western anticline adjacent to the syncline is a crest-like fold that is morphologically similar to the syncline. The anticline apexes dip distinctly to the south; the syncline apexes dip to the north. This is apparently due to the secondary gentle plunging of the folding surface to the north at gentle synclines. The competent sandstone bed is broken in some places and mudstones are folded. The rocks have numerous, almost flat layered sliding planes with sublatitudinal hatching.

The Unkurda object (4). In the area of the village of Unkurda (near the central segment of the allochthonous plate of the Karantrav thrust), the flysch of the Middle Carboniferous Maloikskaya Formation, which is folded into associated west vergent overturned folds, is uncovered in a quarry (Fig. 8). The fold limbs dip to the east: the common limb with normal bedding of layers has a gentle dip (30°), while the overturned limb has a steep dip (75°). Thus, the axial fold planes dip to the east at an angle of 50°–55°. The east wing of the syncline is traced for a few meters, while the deposits have a vertical bedding.

The Karantrav object (*5*). To the south of the village of Karantrav (near the southern segment of the Karantrav thrust, the allochthonous plate) the flysch of the Upper Carboniferous Vaselga Formation (Fig. 9) is uncovered in a quarry. The deposits have near vertical bedding (a dip azimuth of 280° and a dip angle of 80°) and they are likely to make up a steep limb of the large inclined fold. As observed in the village of Karantrav the flysch deposits of the Vaselga Formation are flat lying (20°–30°), which probably allows one to attribute them to a gentle fold limb.

Discussion of material. The length of this article does not allow us to give a detailed description of all of the studied structures. However, we have described the most interesting objects, which provide a sufficient idea of the paragenesises of various structural elements within the Ufimian amphitheater. The first issue that one notes is the distinct western vergence of all of the elements. The axial planes of the majority of folds are curved and become gentler westward in the upper parts of the folds; they form the axial planes of unique drag folds.

During the study of the textural features of flysch formations, the occurrence of a large number of sites with vertical bedding (submeridional) was revealed, which leads to an ambiguous interpretation. At first glance, this situation does not conform to the idea of the thrust structure of the region. However, in well-exposed sites, where a general structural pattern is observable, it became evident that beds with vertical or near-vertical bedding (in both normal and overturned positions) form the limbs of inclined or overturned folds; the adjacent limbs are usually flat lying (Urakovka,

Fig. 7. The textural features of the flysch deposits of the Chigishan Formation, 2 km southeastward of the village of Urakovka. Marker horizons of folds are shown by dotted lines; dashed line show a fault plane.

Fig. 8. A photo of an overturned fold in the flysch deposits of the Maloikskaya Formation near the village of Unkurda. Marker horizons of folds are shown by dotted lines; the chain-dotted line shows the position of a fault plane.

Fig. 9. Flysch deposits of the Vaselga Formation southward of the village of Karantrav. The bedding of rocks is near vertical. This is probably a limb of an inclined fold.

Unkurda, etc.). In connection with this, we suggest that other sites with vertical bedding of deposits (Kurga, Karantrav, etc.) are the limbs of inclined folds.

The strongest deformations of the flysch are manifested in the autochthonous plate close to the main fault plane of the Karantrav thrust. This is expressed in the formation of a partially structured tectonic mélange, where the competent sandstone beds are broken into separate fragments, including fragments of isoclinal folds (Kalinovka). All of these fragments are surrounded by a matrix made of schistose siltstone. The structuredness of the melange is expressed in the total gentle dipping of all its elements to the east, including the axial planes of isoclinal folds. It is likely that many other sites of distribution of the flysch deposits that seem to be unstructured but always show gentle schistosity occupy the same structural position.

Horizontal folds complicated by local thrusts parallel to their axial planes (Kalinovka) occupy the same position relative to the fault plane of the Karantrav thrust.

Of particular interest is the fact that on the background of the general submeridional strike of the majority of structures, the specific dips and strikes of these elements are quite diverse. Thus, the dip azimuths of the axial planes of folds and gentle faults range from the southeast to the southwest, sometimes within a single object.

The reason for this probably lies in the fact that a strike-slip component that is caused by non-uniform movement of the allochthon played a significant role during thrusting. However, the strike of the structural elements is almost always conformable to the strike of the Karantrav thrust fault plane.

CONCLUSIONS

An analysis of the mesoscale structural elements of the Karantrav fault zone confirms its overthrust nature. The degree of rock dislocation, as expressed in the complexity and diversity of the mesoscale structural elements, is in direct relationship to the distance to the thrust fault plane. Near the fault plane the degree of dislocation reaches the maximum and it decreases with an increase in the distance from the plane. The thrusting was uneven and its direction changes slightly over time. In addition, the thrust front probably was a broken line. This is one reason that various structural elements associated with the Karantrav thrust have different orientations. However, they always have an eastern strike and are conformable to the fault plane.

Thus, structural parageneses that developed in compression environments in combination with local transgressions have been reliably determined within the Karantrav thrust zone.

Paragenesis no. 1, which is located in the autochthon directly near the fault plane, has the following elements: a structured tectonic melange, isoclinal overturned folds with west vergent gently-dipping inclined axial surfaces, recumbent folds, small disharmonic folds, local thrusts, flat-lying foliation, and horizontal slipping planes.

Paragenesis no. 2 was identified at some distance from the fault plane both in the autochthon and allochthon. It comprises inclined asymmetrical folds (one of the limbs is very steep to vertical), which often pass into overturned folds with a curved west vergent axial fold plane; gentle faults; local thrusts and overthrusts; and a schistosity zone.

Paragenesis no. 3 can be rarely found in the autochthon at a distance from the Karantrav thrust. It is similar to paragenesises no. 2: inclined open folds with rounded hinges, which are often carinate and crest like. The folds are accompanied by schistosity zones and local thrusts.

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Translated by D. Voroshchuk