Tectonics of the Central Part of the Adycha-Taryn Fault Zone (Verkhoysk-Kolyma Orogenic Belt, NE Asia)

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Abstract. The study area is located in the central part of the regional-scale Adycha-Taryn fault zone separating the Adycha-El’gi and Nera anticlinoria in the hinterland of the Verkhoysk fold-and-thrust belt (central part of the Verkhoysk-Kolyma orogenic belt). Detailed structural studies were conducted in large quarries in the lower reaches of the El’gi River (Indigirka R. basin). In the Adycha-El’gi anticlinorium, several generations of folds, faults, and cleavage are recorded. The intensity of deformation here is found to gradually increase in NE direction. The NE wall of the Adycha-Taryn fault is thought to be more strongly deformed. The results of our investigations revealed three structural parageneses. The first paragenesis includes thrusts, reverse faults, and intense NW-striking folds of the first generation. The second paragenesis consists of less intense superposed folds of the second generation, with subvertical axes, as well as sinistral strike-slip faults. The previously made assumption is confirmed about manifestation in the study area of at least two deformation stages. We also presuppose the existence of the third deformation stage in which dextral strike-slip faults were formed. A change in the intensity of tectonic deformations both along and across the Adycha-Taryn fault zone is first established. On the southwestern side of the fault zone, the intensity of deformation structures decreases from NW to SE. On the northeastern side, the deformation intensity first increases in that same direction but then tends to diminish. An assumption is made about a growing importance of reverse faults in NW direction, along the Adycha-Taryn fault zone. Orientation of paleostress axes responsible for the formation of tectonic structures in the study area is first determined. Folds and thrusts of the first deformation stage were formed under subhorizontal compression in NE direction. Sinistral strike slips and associated folds of the second deformation stage resulted from WE-oriented subhorizontal compression. The following dextral strike-slip motions occurred in the conditions of NW-directed subhorizontal compression and NE-oriented subhorizontal extension. The studied tectonic deformations were formed in Late Mesozoic time as a result of collision-accretion events in the central part of the Verkhoysk-Kolyma orogenic belt.

1. Introduction

The study area is located in the lower reaches of the El’gi River, a left-side tributary of Indigirka. Detailed structural studies were conducted in large technogenic quarries situated along the Kolyma road. Tectonically, the territory is in the central part of the zone of influence of the regional-scale Adycha-Taryn fault (ATF), in the central sector of the Verkhoysk-Kolyma orogenic belt. The early authors considered this fault as separating the Adycha-El’gi anticlinorium in the hinterland zone of the Verkhoysk fold-and-thrust belt from the Nera block (anticlinorium) of the Kular-Nera terrane [1].
Investigations carried out at a later time showed that the Nera block forms part of the hinterland zone (figure 1A). On the southwest wall of the ATF, in the Adycha-El’gi anticlinorium, there are recognized several generations of folding, faulting, and cleavage. Here, the intensity of deformation is found to increase gradually in NE direction [1]. The northeast wall of the ATF is considered to have undergone stronger deformation [2]. The fault is poorly exposed but can well be traced on space imagery. In the geological structure, it is established from the growing intensity of folding and faulting, position of Cenozoic basins. The ATF is believed to have originally reverse-fault kinematics but later was transformed into a sinistral strike-slip fault with elements of transpression and transtension [2]. The studied tectonic deformations were formed in Late Mesozoic time as a result of collision-accretion events in the central part of the Verkhoyansk-Kolyma orogenic belt. Confined to the ATF zone is the Taryn metallogenic zone extending northwestward for 500 km. It contains numerous Au-Sb and less abundant Ag and Ag-Sn polymetallic deposits and occurrences. The Sarylakh and Sentachan Au-Sb deposits discovered here are unique in tonnage and metal concentrations [1].

Figure 1. Location of the study area (A) and geological map of the east wall in the central part of the Adycha-Taryn fault zone (B).

KOM – Kolyma – Omolon superterrane, VFB – Verkhoyansk fold-thrust belt, OChVB – Okhotsk-Chukotka volcanic belt

 Deposits: 1 – Quaternary, 2 – Middle Jurassic, 3 – Lower Jurassic, 4 – Upper Norian, 5 – Lower Norian, 6 – Upper Carnian, 7 – Lower Carnian; 8 – rhyolite porphyry dikes of presumable Late Jurassic age, 9 – quartz-diorite porphyrite dikes of presumable Late Jurassic age, 10 – faults, a – unidentified kinematics, b – thrusts, 11 – axis of anticline, 12 – axis of syncline. Black square in diagram A shows location of the study area.
2. Folds and faults
The major fold structures of the study area are the NW-striking El’gi anticline and the more southwesterly Tordochan syncline. The El’gi anticline is larger in size, with a width of 12–15 km and a length of more than 100 km. Its northeast limb is gentle, the dip angle ranges widely from 40 to 80°; the southwest limb is steeper, with a dip angle of 80–90°. The rock bedding in the SW limb varies from normal to overturned. No small-scale folds have been found in the exposures on the NE limb of the anticline. The geological mapping revealed similar and concentric undulating folds and gentle, wide concentric and box folds. Microfolding of plastic clay strata is locally recorded [3]. The Tordochan syncline is 4–8 km wide and over 40 km long. Its northeast limb, concurrently forming the limb of the El’gi anticline, is steeper than the southwest limb where the rocks dip at 40–70°. These folds deform Upper Triassic clastic rocks dominated by mudstones and siltstones, with subordinate amounts of fine-grained sandstones and conglomerates. The importance of coarse-grained rocks tends to increase up the Carnian-Norian section. The crest of the El’gi anticline consists of Lower Carnian rocks, while the trough of the Tordochan syncline is composed of Lower Norian strata (figure 1B). The limbs of the folds are made up of Upper Carnian rocks. Northeasterly, in the trough of the Uduma syncline there are exposed Lower and Middle Jurassic rocks unconformably overlying Upper Triassic strata [4].

![Figure 2](image.jpg)

**Figure 2.** Asymmetric folds of the first generation in the central part of the Tordochan syncline (A) and stereogram of poles to bedding for the first-generation folds (B).

Dashed lines on photo (hereafter): white – bedding, red – fault. On stereogram (hereafter) – equal-angle projection, lower hemisphere, n – number of measurements.

Several generations of folds and faults are recognized here. The first-generation folds of NW strike are, for the most part, asymmetric, rarely symmetric, sometimes overturned to NE (figure 2A). The fold hinges are slightly inclined or subhorizontal. Anticlines and synclines with steeper NE and SW limbs, respectively, predominate. The folds are linear and undulating; conical forms are prevalent, though cylindrical folds are also found. Judging by the form of crests and troughs, the folds are mostly oblique, rarely upright and closed. Occasionally, open and tight folds are encountered. The folding is concentric; the size of the folds varies from a few centimeters to a few tens of meters. In this generation belong the El’gi anticline and Tordochan syncline. Based on the carried out measurements of the bedding orientation, we estimated the averaged axis of folding plunging to NW (dip az. 316°) at ß 27° (figure 2B). Folds of the first generation are often accompanied by non-penetrative cleavage mainly manifested in mudstone and siltstone units. Its intensity grows with the decreasing granularity of the rocks, reaching its maximum in mudstones. There are observed cases of cleavage refraction manifested at the contacts of layers with contrasting competence. The strike of the cleavage is nearly parallel to that of the folding.
Figure 3. Symmetric fold of the second generation (A) in the central part of the Tordochan syncline and relationships between folds of different generations (B) in the southwest part of the Tordochan syncline. For symbols see figure 2.

Figure 4. Bedding-plane thrust duplex (A) in the central part of the Tordochan syncline and a reverse fault cutting a fold of the first generation (B) on the southeast wall of the El’gi anticline. For symbols see figure 2.

The folds of the second-generation are less pronounced. They are symmetric, rarely asymmetric, with steeply (60–70°) inclined hinges (figure 3). These folds are linear, cylindrical, with no undulation. The folding is, in general, concentric. The size of the folds ranges from 1–2 to 6–7 m.

The first generation of faults is dominated by thrusts. Bedding-plane faults are widespread (figure 4A). The strike of the thrusts ranges widely, but the main directions are NW and NE (figure 5A). Dip angles vary from 40 to 90° (avg. 60°). The thrusts are normally structurally and genetically related to the first-generation folds, and form locally small fault-propagation folds. Sometimes, the folds and thrusts of the first generation are found to be displaced by major reverse faults (figure 4B). The amplitude of displacement on the thrusts varies from a few centimeters to a few tens of meters.
Figure 5. Stereograms of poles to faults: A – thrusts, B – sinistral strike-slip faults, C – dextral strike-slip faults, D – quartz veins. For symbols see figure 2.

The second generation of faults includes strike slips. In the studied exposures, sinistral strike-slip faults with ENE and NNW strike predominate (figure 5B). The dip angles are 75–90°, less frequently 40–50°. Dextral strike-slip faults are less common. They have mainly a NW or sublatitudinal strike (figure 5C) and steep dip angles (70–90°). Sometimes they displace the planes of sinistral strike slips. One can observe combinations of strike slips, both sinistral and dextral, with other fault types, primarily with reverse faults. The amount of displacement on the strike-slip faults is difficult to determine. We observed, however, in the exposures strike slips with the amplitude of displacement from a few tens of centimeters to a few meters. Normal faults are extremely rare in the study area. We have found only one sublatitudinal steeply dipping normal fault with a sinistral strike-slip component, which indicates it is in structural paragenesis with a strike-slip fault.

There are numerous extension fractures filled with quartz veins of various strike among which those of NE strike prevail (figure 5D). The vein thickness ranges up to a few tens of centimeters. Occasionally, veins deformed into asymmetric folds of the first generation can be found. Measurements of the elements of orientation of the veins and observation of their relationships permitted us to calculate the axes of paleostress fields in four localities (figure 6). For each locality, we outlined conjugate vein systems and constructed stereograms with calculated paleostress axes (Table 1). The method we used is based on the conception that the intersection point of the great-circle projections of conjugate fractures on the Wulff net corresponds to the intermediate axis of principal normal stresses [5]. Hancock and Kadhi [6] showed that in a conjugate shear fracture system (in our case veins) the compression axis bisects the smallest dihedral angle. We propose the existence of at least two generations of veins in the study area. The first (the earliest) generation includes veins deformed into folds. The second generation is represented by veins formed under subhorizontal (≤72–11°) extension in NW direction (strike az. 308–322°). The compression axis is steeply (≤51°) inclined or subvertical (≤74°). Veins formed in this paleostress field are the most abundant and observed in the more northeasterly localities (Loc. 1 and 2) (figure 6). It appears that precisely this generation of veins is associated with the first-generation folds. In the immediate vicinity to the ATF zone (Loc.3 and 4),
there occur several vein systems characterized by variously oriented paleostress axes. Variations in orientation are likely due to later superposed strike-slip deformations.

**Figure 6.** Stereograms with poles to conjugate veins, an auxiliary great-circle path and calculated paleostress axes. T – extension axis, P – compression axis. For symbols see figure 2.

Based on the orientation of striae on the slickensides of small faults and on their kinematics we also calculated principal axes of paleostresses [7]. Since we presuppose the existence in the study area of several deformation stages characterized by certain types of faults, we calculated principal paleostress axes separately for each fault type in each of the studied localities. As a result, we obtained orientations of paleostress axes for several generations of faults, which are shown in Table 2. In the study area, two generations of thrusts and strike-slip faults are identified. The first (main) generation of thrusts, most probably associated with the formation of the first-generation folds, developed as a result of subhorizontal (∠12°) compression in EN direction (dip az. 222°). The extension axis is subvertical (∠77°) (figure 7A). Concurrently with these thrusts, both sinistral and dextral slips of the first generation were likely formed (figure 7C, E). These were followed by sinistral strike slips of the second generation that developed under conditions of subhorizontal (∠12°) compression in WNW direction (dip az. 287°). The extension axis is subhorizontal (∠12°) and longitudinally oriented (dip az. 18°) (figure 7D). It is probably to these deformations that the second-generation folds were related. A change to subhorizontal (∠0.3°) NW-directed (dip az. 326°) compression resulted in the formation of dextral strike slips of the second generation. The extension axis dips to NE (dip az. 56°) at an acute
The formation of the second-generation thrusts remains debatable (figure 7B). They probably developed in association with strike-slip faults of later generations, but in this case it should be borne in mind that later deformations changed the position of early faults in space. Thus, the estimated orientation of paleostress axes for dextral strike slips, as the latest-formed faults, may be considered the most reliable. Differences in the orientation of paleostress axes between dextral and sinistral strike slips and observations made by previous researchers in adjacent areas suggest the existence of the third dextral strike-slip stage of deformation. Since dextral strike slips are very rare in occurrence and appear not to have a profound effect on the general tectonic framework of the territory, the calculated paleostress axes for the sinistral strike slips can also be considered reliable. Coordinates of paleostress axes obtained for thrusts seem to be the least precise.

### Table 1. Orientation of paleostress axes for conjugate vein systems.

| Loc. | n | Axes | Tension (1) | Intermediate (2) | Compression (3) |
|------|---|------|-------------|------------------|-----------------|
|      |   | Azimuth |            | Azimuth |          | Azimuth |          |
| 1    | 5 | 128.4 | 2.3 | 36.5 | 38.4 | 221.3 | 51.5 |
| 2    | 7 | 321.7 | 11.3 | 54.1 | 11.7 | 188.8 | 73.6 |
| 3 – 1 | 6 | 125.3 | 58.8 | 256.1 | 21.6 | 355.0 | 21.4 |
| 3 – 2 | 4 | 280.5 | 7.2 | 23.5 | 60.7 | 186.6 | 28.2 |
| 3 – 3 | 5 | 310.1 | 41.8 | 157.2 | 44.9 | 52.9 | 14.0 |
| 4    | 7 | 205.5 | 52.9 | 90.9 | 17.5 | 349.7 | 31.5 |

### Table 2. Orientation of paleostress axes for faults.

| Faults | n | Axes | Tension (1) | Intermediate (2) | Compression (3) |
|--------|---|------|-------------|------------------|-----------------|
|        |   | Azimuth |            | Azimuth |          | Azimuth |          |
| Thrust (1) | 8 | 57.9 | 77.2 | 313.0 | 3.4 | 222.3 | 12.4 |
| Thrust (2) | 3 | 307.7 | 74.0 | 58.0 | 5.7 | 149.5 | 15.0 |
| Sinistral strike-slip (1) | 12 | 304.9 | 3.8 | 148.2 | 85.8 | 35.0 | 1.6 |
| Sinistral strike-slip (2) | 10 | 17.7 | 12.4 | 190.7 | 77.5 | 287.4 | 1.5 |
| Dextral strike-slip (1) | 3 | 285.6 | 26.7 | 107.6 | 63.3 | 16.0 | 0.8 |
| Dextral strike-slip (2) | 4 | 55.8 | 20.8 | 234.8 | 69.2 | 325.7 | 0.3 |

Last century, tectonic deformations along the ATF zone were studied only in separate points, but in close detail [2, 8, 9]. Special structural studies along the Nelgese River, flowing into the middle Adycha River, revealed several deformation stages on either wall of the ATF zone. The earliest stage is marked by the formation of cylindrical tight folds with a great thickness of rock layers at the cores and almost vertical axial surfaces. The superposed deformation is due to thrusts and later strike slip faults. In the thrust zones, isoclinal recumbent folds are documented [8]. A similar situation is observed in the upper reaches of the Adycha River. Here, two stages of deformation (two generations of folds) are recognized in both walls of the ATF. During the first stage, most of the folds and associated thrusts developed. The second stage was marked by the formation of reverse-strike-slip faults and the ATF zone proper. Associated with strike slips were small folds with subvertical hinges. The ATF zone is outlined here as the Bylyn’ya block. The block is dominated by reverse faults cut by sublatitudinal sinistral strike slips with steep to subvertical dip angles mainly toward north [9].

Previously, detailed structural studies were conducted on either wall of the central segment of the ATF, in the middle El’gi River and the lower reaches of its tributaries, Tobychan and Arangas, as well
as on the right bank of the lower El’gi River. Researchers focused their attention on the fact that Triassic rocks in the northeast wall of the fault are more intensely deformed as compared to its southwest wall. Four generations of folds and two generations of cleavage are established in the northeast wall. In the southwest wall, on the right bank of the lower El’gi River, the fold structure gets simpler. Cleavage is also present but its intensity is weakened. The faults are mostly concentrated in the NE wall of the ATF. Two generations of thrusts and two generations of strike slips are manifested here. Strike slips are mainly clustered in the NE wall, while thrusts occur in both of the walls [2].

![Figure 7](image)

**Figure 7.** Stereograms of great-circle paths of fault planes with calculated paleostress axes.

Arrow shows the movement of the hanging wall. T – extension axis, P – compression axis. For symbols see figure 2.

These data and the results of our investigation show that in the area from the middle Adycha River to the El’gi River mouth the intensity of deformation changes both across and along the ATF zone. In the SW wall of the fault, one can observe a reduced intensity and simplification of the folding structure from NW to SE. In the NE wall, the degree of deformation first increases toward the middle El’gi River and then tends to decrease further southeastward (lower El’gi River). Within the ATF zone itself, the number of reverse faults is supposed to grow in NW direction.

### 3. Conclusions

Tectonic structures exposed in technogenic exposures on the left bank of the lower El’gi River are first described, which improved and supplemented significantly the available information on the tectonics of the central part of the ATF zone (central sector of the Verkhoyansk-Kolyma orogenic belt). Two structural parageneses are recognized here. The first one includes thrusts, reverse faults, strike slips, and the first-generation folds. The second parageneisis comprises folds of the second generation and sinistral strike-slip faults. An early assumption is confirmed about manifestation of at least two deformation stages in the study area [9]. Complex and intense folding of the first stage has a NW strike. It appears that prevalent thrust-reverse fault deformations were accompanied by rather intense sinistral strike-slip faulting and the formation of most of the quartz veins. The superposed sinistral strike-slip deformations were attended with less intense folds with subvertical hinges. An assumption is made about the existence of the third deformation stage characterized by the formation of dextral
strike slip faults. We first established a change in the intensity of tectonic deformations not only across but also along the ATF zone. In the SW wall of the zone, the intensity of deformation weakens from NW to SE. In the NE wall, deformation gets stronger toward the middle El’gi River but then tends to reduce southeastward (lower El’gi River). It is assumed that in the ATF zone the reverse fault component grows in importance in NW direction. Orientation of the axes of paleostresses that caused the formation of tectonic structures in the study area is first estimated. The first deformation stage is dominated by thrusting caused by subhorizontal compression in NE direction. Orientation of paleostress axes estimated for this stage is the least precise. Structures of the second deformation stage are represented by sinistral strike-slip faults that formed in the conditions of sublatitudinal subhorizontal compression and sublongitudinal extension. The following dextral strike-slip deformations resulted from subhorizontal NW-directed compression and slightly inclined NE-oriented extension.

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