Tectonic Structures in the Southeastern Flank of the Junction Zone Between the In’yali-Debin Synclinorium and the Omulevka Terrane (Kolyma-Omolon Microcontinent, NE Asia)

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Abstract. The study area is located in the zone of junction of the In’yali-Debin synclinorium and the Omulevka terrane (Kolyma-Omolon microcontinent of the Verkhoyansk-Kolyma fold belt). The main tectonic structure is the Momontai syncline made of Middle Jurassic clastic rocks overlain by Upper Jurassic volcanic and volcanoclastic rocks of the Uyandina-Yasachnaya volcanic arc. The Au and Au-Ag occurrences known here are confined to NE-trending faults and hosted in subvolcanic and volcanogenic rocks, mainly rhyolites and dacites. The studied Middle Jurassic rocks are found to be characteristic of near-shore shelfal environments changing, in certain time intervals, to deltaic conditions of sedimentation. The presence in the conglomerates and sandstones of large poorly rounded quartzite and carbonate fragments and of mudstone and volcanic pebbles indicates a proximal provenance of the clastics. For the first time we established a sharp angular unconformity between the intensely deformed Middle Jurassic and Upper Jurassic rocks in the region. Relations between the Late Jurassic subvolcanic deposits and the host rocks were studied. The carried out structural and tectonophysical investigations showed that folding occurred in two deformation stages. During the first stage, the Middle Jurassic clastic rocks were draped into small recumbent to isoclinal folds, cylindrical and parallel-type, with a NW strike. Cleavage is rare. The structural paragenesis of bedding-plane detachment faults, thrusts, normal faults, and strike slip faults is found to have formed in a single stress field together with the development of folds of the first deformation stage. The intensity of the first-stage folding increases from west to east. Restored are axes of paleostresses responsible for the formation of fold-and-thrust structures of the first deformation stage. The Upper Jurassic volcanogenic-sedimentary strata were deformed into superposed large, simple, open folds of the second stage, which exhibit sublatitudinal orientation. They associate with small-scale thrusts and, rarely, strike-slip faults. It is recognized that in the late Middle Jurassic or the early Late Jurassic the region was affected by intense folding which produced tectonic structures of NW strike. Accumulation of the Late Jurassic volcanogenic rocks and intrusion of subvolcanic deposits occurred on/into the earlier deformed Middle Jurassic rocks.

1. Introduction

The study area is located in the zone of junction of the In’yali-Debin synclinorium and the Omulevka terrane (Kolyma-Omolon microcontinent of the Verkhoyansk-Kolyma fold belt). Studies were conducted in the Momontai and Urultun interfluve and along the Ulbutakan R., a tributary of Urultun.
The main tectonic structure is the Momontai syncline made of Middle Jurassic clastic rocks overlain by Upper Jurassic volcanic and volcaniclastic rocks of the Uyandina-Yasachnaya volcanic arc [1] (figure 1). The syncline is about 30km wide and over 80km long. On its northeastern limb there are known Au and Au-Ag occurrences hosted in subvolcanic and volcanogenic rocks of Upper Jurassic age. Mineralization is confined to a system of NE-trending faults. The aim of our studies was to obtain more data on the lithology and sedimentology of the Middle to Upper Jurassic clastic, volcanic, and volcaniclastic rocks and to define the nature and sequence of formation of tectonic structures in the region.

**Figure 1.** Tectonic sketch map of NE Asia showing studied location (black rectangular) (Kolyma – Omolon microcontinent: PT – Prikolyma terrane, OT – Omolon terrane, O – Omulevka terrane, AT – Arga-Tas terrane, ZB – Zyryanka basin; Verkhoyansk fold-and-thrust belt: PS – Polousnyi synclinorium, ID – In’yali-Debin synclinorium, WV – West Verkhoyansk; SAS – South Anyui suture) (A) and geological map of NE limb of the Momontai syncline (Deposits of: 1 – upper sequence of the Lower Jurassic, 2 – lower sequence of the Middle Jurassic, 3 – middle sequence of the Middle Jurassic, 4 – Sumun Fm., Oxfordian and Kimmeridgian stages of the Upper Jurassic, 5 – lower member of the Serganiya Fm., Volgian stage of the Upper Jurassic, 6 – upper member of the Serganiya Fm., Volgian stage of the Upper Jurassic, 7 – Quaternary; 8 – Late Jurassic subvolcanic rhyolites, 9 – faults, defined and assumed. Circled numbers – areas of detailed study) (B).
2. Stratigraphy, lithology, and sedimentology

Middle Jurassic deposits are represented in the study are by the lower ($J_2^1$) and middle ($J_2^2$) sequences [1].

*The lower sequence* ($J_2^1$) includes interbedded siltstone, cherty mudstone, sandstone, gritstone, conglomerates, and clastic breccias. In sandstones and siltstones one can observe load-cast structures on the underside of the beds, traces of convolute lamination, and different-scale cross bedding. Conglomerates contain lenses of cherty mudstone and fragments of wood and organic detritus. The sandstone beds sometimes include large (up to 0.4–1m) blocks of carbonate rocks. Present are underwater channels which are traces of ancient streams cutting the underlying deposits. Hummocky cross-stratification is well developed (figure 2, A).

![Figure 2](image)

**Figure 2.** Hummocky cross-stratification (A); interbedded siltstone, sandstone, and cherty mudstone (B); clastic breccias at the base of Sumun Fm. (C); tuffs in the Serganiya Fm. (D).

*The middle sequence* ($J_2^2$) comprises interbedded siltstone, sandstone, and cherty mudstones (figure 2, B). The rocks are characterized by cross bedding and the presence of load casts and sometimes tempestites and organic detritus.

Upper Jurassic deposits are represented by two formations – Sumun ($J_3^{sm}$) and Serganiya ($J_3^{sr}$) [1].

*Sumun Formation* ($J_3^{sm}$) overlies, with a sharp angular and, possibly, stratigraphic unconformity, the subvertically oriented clastic rocks of Middle Jurassic age (figure 3). It should be noted that such a well-exposed unconformity at the base of Upper Jurassic volcanites is unique in the region. At the base of the formation there are present clastic breccias ranging up to 2m thick (figure 2, C), which change laterally to conglomerates and gritstones composed of poorly rounded clasts, among them fragments of the underlying terrigenous rocks and volcanites. The matrix of the rocks has, most likely, a volcanogenic (pyroclastic) nature. It is probable that the rocks are lahars that originated during the
onset of eruptions on the slopes of a paleovolcano. The formation is made of rhyolite, rhyodacite, rhyolitic porphyry and, rarely, acid tuffs and lava breccias. Tuff breccias, tuffaceous sandstones, and andesites are also present in the section.

Figure 3. Angular unconformity between vertical Middle Jurassic clastic rocks and gently dipping Upper Jurassic volcanogenic rocks (A, B).

Dashed lines: white – bedding, yellow – contact

*Serganiya Formation* (*J*sr) is represented by dacite, dacite porphyry, felsic tuffs, and, rarely, tuff lavas, elastic breccias and tuffaceous sandstones and mudstones. The tuffs have a banded structure (figure 2, D). The upper part of the section of the Serganiya formation is characterized by columnar joints forming hexahedral and pentahedral prisms up to 0,5m thick. The total thickness of the studied Upper Jurassic strata exceeds 1200m.

3. Fold structures

Small-scale folding is widely manifested in the Middle Jurassic deposits of the NE limb of the Momontai syncline. The rocks are draped into tight asymmetric concentric, cylindrical and, rarely, conical folds with widely varying amplitude and width from a few to tens and hundreds of meters. Common are large SW-recumbent to isoclinals folds as seen from extensive outcrops in which the rocks have an overturned bedding (figure 4). The fold hinges are both subhorizontal and rather steeply dipping (20-25°). The folds of the Middle Jurassic rocks have a NW strike just like the main deformation structures of the Verkhoyansk-Kolyma fold belt (figure 5, A). Cleavage occurs rarely and is conformable to folding (figure 5, B). It is not pervasive and seen only in siltstone and mudstone beds. No cleavage is observed in massive sandstone units. The intensity of folding increases in an eastward direction. The folds are mainly SW-vergent.

The Middle Jurassic strata are cut by subvolcanic rhyolite and dacite bodies of Late Jurassic age (figure 6).

The intensely deformed Middle Jurassic rocks are overlain, with the above described sharp angular unconformity, by gently pitching Upper Jurassic volcanites (figure 3). The Upper Jurassic rocks are in turn, deformed into open folds up to several kilometers wide. One such anticline is located in the Ulbutakan - Pravy Ulbutakan – Chara interfluve (figure 7). Its limbs have dip angles of about 30°. The anticline is symmetric, cylindrical, with a subhorizontal (±2°) axis of sublatitudinal strike (dip az. 273°) (figure 5, C).
Figure 4. Selected photo showing folds and thrusts observed in the Middle Jurassic rocks on NE limb of the Momontai syncline (A–D).

Dashed lines: white – bedding, red –fault

Figure 5. Diagram of pole to bedding of Middle Jurassic clastic rocks (A), to cleavage (B) and to bedding of Upper Jurassic volcanic and volcaniclastic rocks (C) (equal-area projection, lower hemisphere; n – number of measurements)

Folding of volcanites is discordant to orientation of folds of the Middle Jurassic rocks. Thus, the Middle and Upper Jurassic rocks, separated by an angular unconformity, are deformed in different ways, which indicates, at least, two deformation stages manifested in the region.
Figure 6. Contact of a late Jurassic subvolcanic rhyolite body with subvertical sedimentary rocks of the Middle Jurassic (A, B).
Dashed lines: white – bedding, yellow – contact

Figure 7. Upper Jurassic volcanic rocks deformed into anticline (A), columnar joints in volcanic rocks of the Upper Jurassic Serganiya Fm. (B).
Dashed lines: white – bedding, blue – columnar joints

4. Faults
The most abundant faults in the Middle Jurassic rocks are NW-trending thrusts and bedding-plane detachment faults (figure 8). With the general SW vergence of folding in the Middle Jurassic strata, the thrusts dip both to the NE and SW (figure 9, A). The amplitude of displacement on the thrusts is estimated to be from several tens of centimetres to a few tens of meters. Sinistral and dextral strike-slip faults are present, often with a thrust and normal fault components. The trends of the strike slips vary within a wide range.

The dextral strike-slip faults have mainly W-NW and E-NE trends (figure 9, B). The sinistral strike slips trend mainly towards NW and, less frequently, NE (figure 9, C). Orientation of the strike-slip faults implies they are transfer faults related to thrusts. The amount of displacement on the strike-slip faults is difficult to determine.

Normal faults are less common. They have generally W-NW and NE trends (figure 9, D). The amount of displacement on them is small – up to a few tens of centimeters.
Figure 8. Selected photo showing folds and thrusts observed in the Middle Jurassic rocks on NE limb of the Momontai syncline (A, B).

Dashed lines: white – bedding, red – fault

Figure 9. Pole to faults diagrams.

A – thrust, B – dextral strike-slip fault, C – sinistral strike-slip fault, D – normal fault, E – thrusts in Upper Jurassic volcanogenic rocks, F – tectonic jointing in volcanogenic rocks. Black dashed line shows dominant trend of faulting (equal-area projection, lower hemisphere; n – number of measurements)

Faults are extremely rare in the Upper Jurassic volcanogenic rocks. There are mainly thrusts (figure 10), with rare strike-slip and normal faults. The thrusts have mostly a sublatitudinal trend (figure 9, E).

Tectonic joints are most pronounced in the Upper Jurassic volcanogenic rocks, with their strike varying within wide ranges. The predominant direction is NE (figure 9, F).
Figure 10. Selected photos showing thrusts observed in the Upper Jurassic volcaniclastic (A) and subvolcanic (B) rocks
Dashed red line – faults

Figure 11. Faults & striae data diagrams.
Areas: A – 1, B – 2, C – 3, D – 4, E – 5. Arrow shows sense of motion of the hanging wall of fault (equal-area projection, lower hemisphere; n – number of measurements).

5. Paleo-stress field analysis
Based on our measurements of orientation of the fault planes and striae on the slickensides we estimated the compression and tension axes following the technique described in [2]. The number of measurements is 23 for thrusts, 30 for strike slips, and 5 for normal faults. The results are listed on table 1. Observation points are shown in figure 1.
Table 1. Estimated orientation of stress field axes on NE limb of the Momontai syncline.

| Areas | n | Axes          | Azimuth | Azimuth | Azimuth | Azimuth |
|-------|---|---------------|---------|---------|---------|---------|
| 1     | 3 | Tension (1)   | 167.5   | 77.0    | 313.4   | 10.9    |
| 2     | 15| Intermediate (2) | 284.6 | 61.8    | 145.1   | 22.2    |
| 3     | 5 | Compression (3) | 252.8 | 71.7    | 153.3   | 3.1     |
| 4     | 17| Tension (1)   | 79.0    | 67.4    | 293.7   | 18.9    |
| 5     | 18| Intermediate (2) | 7.1   | 54.7    | 141.3   | 26.3    |

It is established that compression axes in all areas have close orientation and are gently inclined (7°–22°) to NE (az. 45°–63°). An exception is the compression axis estimated for Area 2. It is inclined (12°) to N-NE (az. 20°). Tension axes dip steeply (55°–77°) in all areas (figure 11). Thus, the estimated compression axes for tectonic structures of the NE limb of the Momontai syncline are nearly orthogonal to the strike of folds of the first deformation stage.

6. Conclusions

1) A sharp angular unconformity is first established between the strongly deformed Middle Jurassic clastic rocks and Upper Jurassic volcanites.

2) Two stages of deformation are recognized. Intense folding of the Middle Jurassic clastic rocks has NW strike, while the superposed large simple open folds of the Upper Jurassic volcanogenic-sedimentary rocks are EW oriented.

3) It is established that the structural paragenesis of bedding-plane detachment faults, thrusts, normal faults, and strike slips was formed in a single stress field together with the development of folds of the first deformation stage.

4) The studied Middle Jurassic rocks are found to be characteristic of near-shore shelfal environments changing, in certain time intervals, to deltaic conditions of sedimentation. The presence in the conglomerates and sandstones of large poorly rounded quartzite and carbonate fragments and of mudstone and volcanite pebbles indicates a proximal provenance of the clastics.

References

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