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# Structure and Evolution of the Lesnaya Thrust (Northern Kamchatka)

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The Lesnaya thrust on the Kamchatka isthmus is part of the collisional suture separating the Upper Cretaceous complexes of the Achaivayam-Valaginskiy paleoarc from coeval terrigenous complexes of NE Asia continental slope. The formation of the modern structure of the suture zone was initiated by deep thrusts in an allochthonous complex, whose lower plates are made up of green schists and ultrabasite-gabbro bodies. Blastomylonite zones with asymmetric folds were forming at the boundary of the plates; the folds indicated movement of the plates from east to west. Deformations occurred in conditions of extreme warming-up of the crust inherited from the active stage of the arc development. Subsequently these plates were moved onto the surface, and together with the shallower parts of the allochthon were overthrust onto the subaqueous margin of the continent overlain by terrigenous flysch. The autochthonous complex is crumpled into an intricate system of small, differently oriented folds reflecting deformation of the plastic layered thick sequence under conditions of slight predominance of sublatitudinal compression. Low temperature mylonites with pronounced Riedel structures indicating displacement of the allochthon to the northeast parallel to the thrust front are developed along the slip plane. The most plausible explanation of such kinematics is a change of thrusts by NE strike-slip faults at final stages of collision.

## INTRODUCTION

Collision along the northern margins of the Pacific Ocean resulted in the formation of systems of extended tectonic sutures – major elements of the modern structure of perioceanic fold areas. One of the most extended suture of NE Asia is the Vatyna-Andrianovka suture stretching from the Olyutorka zone as far as the southern spurs of the Sredinnyi Range of Kamchatka (Fig. 1). It separates complexes of the Late Cretaceous continental margin from coeval

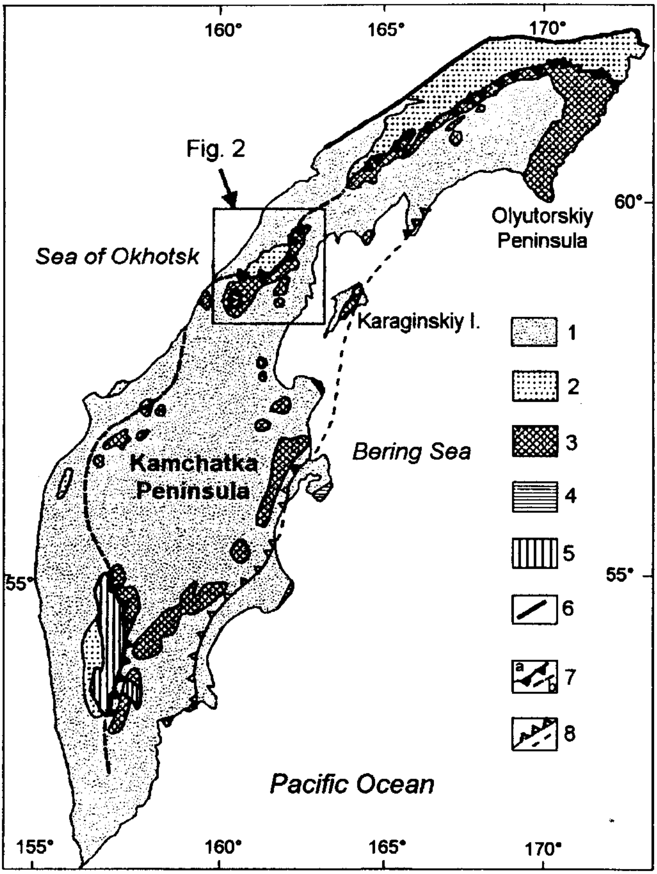


**Fig. 1** Vatyna-Andrianovka suture in the structure of Olyutorka-Kamchatka region.
1 – Cenozoic sedimentary and volcanic rocks; 2-4 – Cretaceous complexes: 2 – terrigenous, 3 –siliceous-volcanogenic rocks of Achaivayam-Valaginskiy arc, 4 - siliceous-volcanogenic rocks of eastern peninsulas (of Kronotskiy paleoarc); 5 – pre-Upper Cretaceous metamorphic rocks; 6 – system of ruptures at the northwestern boundary of Olyutorka-Kamchatka region; 7 – Vatyna-Andrianovka suture (a – observed, b – beneath Cenozoic cover); 8 – suture at the southeastern boundary of Achaivayam-Valaginskiy zone (Grechishkin thrust).

complexes of the Achaivayam-Valaginskiy island arc [3, 9, 17, 19] formed in the ocean at a distance of about 2,000 km from the continent and attached to it in the Cenozoic [10, 12]. The northern part of this suture was first described in the Olyutorka zone as the Vatyna-Vyvenka thrust [11]. Farther the suture was traced on the south, on the Kamchatka isthmus where it was named the Lesnaya thrust [18]. The continuation of this suture is observable in the southern part of the Sredinnyi Range of Kamchatka where it separates the Upper

Cretaceous island arc complexes of the Iruneiskiy and Kirganik suites from the developed more to the west terrigenous thick sequences of the Upper Cretaceous and pre-Late Cretaceous metamorphic rocks. The study of the structure and kinematics of the Vatyna-Vyvenka part of the suture was conducted earlier [13, 14]. This investigation is devoted to the Lesnaya thrust on the Kamchatka isthmus, where the outcrop of pre-Cenozoic rocks form the Lesnaya uplift.

## GEOLOGIC STRUCTURE OF THE LESNAYA UPLIFT

The Lesnaya uplift is framed on the northwest by the West Kamchatka-Koryak volcanogenic belt made up largely of Eocene volcanics of the Kinkil suite; and on the southeast, by the Central Kamchatka volcanic belt, where Miocene and Pliocene volcanics predominate (Fig. 2).

Within the Lesnaya uplift the volcanogenic-sedimentary complexes of the Upper Cretaceous Iruneiskiy suite are overthrust onto the Lesnaya thrust in the northwestern direction where they overlie the terrigenous flyschoid thick sequences of the Lesnaya Group (Upper Cretaceous-Paleogene (?)) [2, 18,

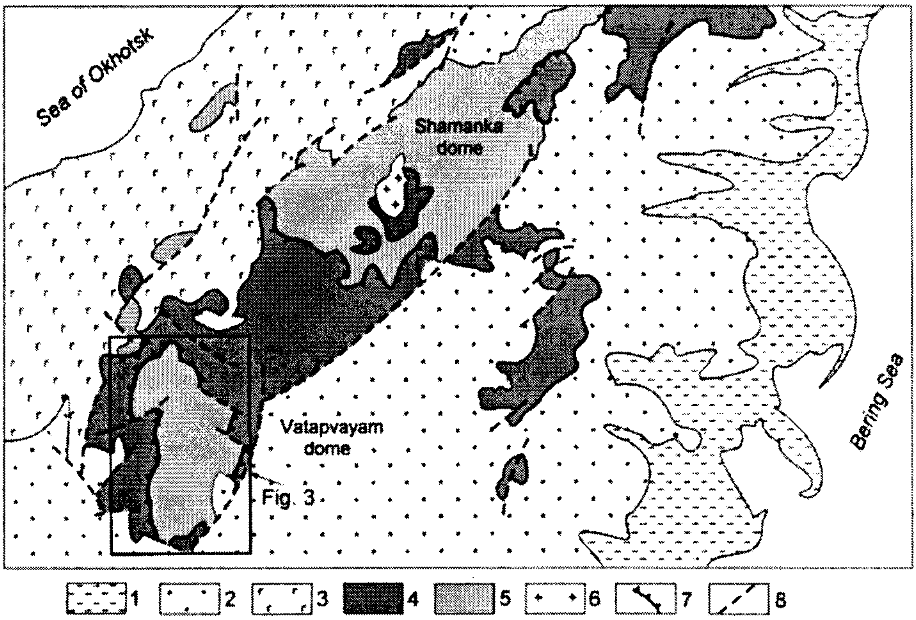


**Fig. 2** Structure of Kamchatka isthmus.

1 – Quaternary deposits; 2 – Central Kamchatka volcanic belt; 3 – West Kamchatka volcanic belt; 4, 5 – Cretaceous outcrop: 4 – Iruneiskiy suite, 5 – Lesnaya Group; 6 – Shamanka massif of mid-Eocene granites; 7 – Lesnaya thrust; 8 – other ruptures.

15]. The base of the allochthon shows locally developed ultrabasite-basite intrusions and schist-quartzite metamorphic assemblages of problematic genesis and age.

The age of the Iruneiskiy suite is acknowledged mainly by finds of inocerams from the *Inoceramus schmidti* group [2], and to a lesser degree, radiolarian determinations [15], and also correlation with the Upper Cretaceous thick sequences of the Olyutorka zone [3]. In all likelihood, the upper horizons of the Iruneiskiy suite are within the lowermost strata of the Paleocene, since the well-dated Upper Paleocene and Lower Eocene of the Palana district of Kamchatka, where outcrop of the typical Iruneiskiy suite are known, are represented by coal-bearing continental molasses [4, 5].

Data on the age of the Lesnaya Group are highly discordant. There is evidence of finds of Santonian-Campanian inocerams in its cherty rocks [2]. Meantime, cherty rocks are atypical of the Lesnaya Group. They occur there as exotic blocks immediately beneath the Lesnaya thrust [20]. They do contain fragments of prismatic layers, and also depleted assemblages of Campanian-Maastrichtian radiolarians have been detected there. However, the nature of the exotic blocks in the Lesnaya Group is debatable, and they can be both older and younger than the flysch matrix. Benthonic agglutinated foraminifers from the Lesnaya suite are taken as Maastrichtian-Danian [2]. In the northern part of the Lesnaya uplift Eocene nanoplankton was detected in the flysch assigned to the Lesnaya Group [15]. Structurally and lithologically, the Lesnaya Group is well correlated with flysch thick sequences of the Ukelayat zone of the Koryak Highland with an age range from the middle Late Cretaceous through the Early Eocene [8, 14], and also with the Upper Cretaceous terrigenous thick sequences of the southern part of the Sredinnyi Range, which are overlain by the Paleocene Cherepanov suite [15]. Southwest of the Lesnaya uplift, on the coast of the Sea of Okhotsk Upper Cretaceous terrigenous thick sequences are also known that are close compositionally to the Lesnaya Group (upper part of the Omgon Group). The Paleocene and the Lower Eocene are represented there by coal-bearing molasses and subaerial volcanics [5]. Proceeding from the whole array of data, we believe that the age of the Lesnaya Group is most likely limited to the Late Cretaceous and Early Paleocene, but we cannot entirely overlook the presence of the Eocene lower horizons in it.

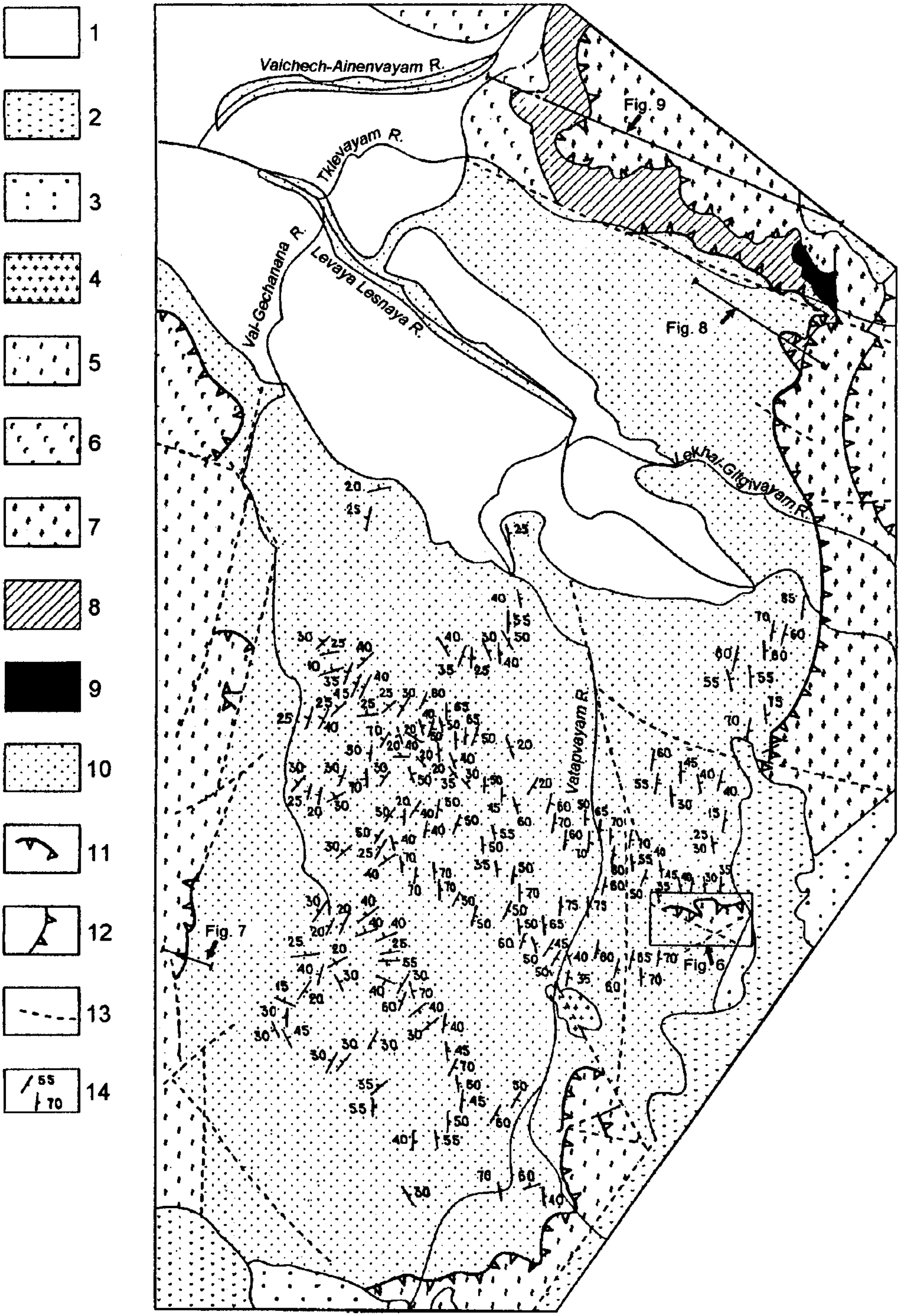
The oldest thick sequence of the neoautochthon, Kinkil suite, made up of subaerial volcanics has an age of Early to Middle Eocene from different estimates based on few isotope determinations and on relations with other Cenozoic units [18, 4]. Thus, the most plausible age range of formation of the Lesnaya thrust falls within the Late Paleocene — Early Eocene.

The inner structure of the Lesnaya uplift is determined primarily by the morphology of the Lesnaya thrust, whose slip plane is complicated by numerous, often steep bends. On the whole, it forms two domes: Shamanka on the north, and Vatapvayam on the south, with outcrop of the Lesnaya Group in the cores, and of the Iruneiskiy suite, on the domal flanks (see Fig. 2). Our data refer to the flanks of the Vatapvayam dome. It represents a submeriodinal antiform 35 m long and 15 km wide (Fig. 3). The core of the fold is made up of the Lesnaya Group, and on the limbs allochthonous complexes of rocks outcrop. On the west and south it is the Iruneiskiy suite proper, and on the northeast they are incremented by assemblages of ultrabasite-basite composition and metamorphic rocks, mainly green schists and quartzites. The most ancient rocks of the Vatapvayam dome belong to the Snatol suite of the Middle Eocene and are made up of sandstones and conglomerates [2]. The emergence of the dome is related to the period after the formation of the Lesnaya thrust: the interval between the Middle Eocene and Late Miocene, since in its eastern side the neoautochthonous Snatol suite virtually follows the dip of the slip plane, and the Miocene-Pliocene effusives occur horizontally.

## METHODS

In the study of deformation of the autochthon and allochthon in the exposures, orientations of bedding planes and cleavage, axes and axial planes of folds were measured and calculated. The construction of ring diagrams and data analysis employed the programs Spheristat v1.1 © Frontenac Wordsmiths (1990) and Quickplot v.1.0 © D. van Everdingen, J. van Gool (1990). All structural elements are shown in the projection on the lower hemisphere on the Schmidt equal-area net (Fig. 4, all units except "f"), and for the planar structures their normals (poles) are shown (Fig. 4, a, b, c). The bends of some folds have been calculated as intersection lines of limb planes (Fig. 4, c) [25]. The V.Kamb method and its modification were used for construction of density isolines of point distribution [26]. The method of eigenvectors was applied for analysis of point distribution [7, 24].

We applied the method of analysis of inner axes of rotation to determine the directions of relative displacements on ruptures (thrusts) [21]. The method is based on the assumption that the idealized fault zone, formed in conditions of progressive deformation of a common strike-slip fault, has a monocline symmetry (Fig. 5). Mesostructural elements are used as kinematic indicators; these elements bear information on the rotation component of deformation, such as asymmetric folds (Fig. 5a) and Riedel structures (Fig. 5b). The Riedel structure is a paragenesis of planar mesostructural elements that forms during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Tklevayam R.
Val-Gechanana R.
Levaya Lesnaya R.
Fig. 9
Fig. 8
Lekhai-Gitgivayam R.
Vatapvayam R.
Fig. 7
Fig. 6

deformation of a common strike-slip fault. The experimental study of Riedel structures showed that displacements occur on three planar elements – Y, P, and R forming in the zone of a brittle strike-slip fault, and the symmetry of these elements is indeed related to the monocline symmetry of deformation [23]. The symmetry plane of the fault zone can be picked up from geometry of structural elements observed in this zone, and the intersection line of the derived symmetry plane and the fault plane determines the displacement vector; incidentally, the direction of displacement of the hanging limb relative to the lying limb is accepted as the direction of this vector.

The orientation of any asymmetric fold or Riedel structure can be represented by the inner axis of rotation bearing information on the direction of rotation (see Fig. 5a, b). Rotation can be lettered "S" or "Z" – rotation counterclockwise or clockwise with respect to the dip direction of the axial vector. In the first case asymmetric folds will have an S-section; in the second case, a Z-section in a plane normal to the axis.

For asymmetric folds the inner axis of rotation is equivalent to the fold axis (see Fig. 5a). For Riedel structures the inner axis of rotation is parallel to the intersection line of the Y-plane and P or R (Fig. 5b). Thus, the inner axis of rotation can be computed from the measured orientations of Y, P, and R. Fig. 5b shows hypothetical distribution of the inner axes of rotation in a strike-slip zone with a monocline symmetry. All the axes must lie near a common plane parallel to the orientation of the fault zone, in which they formed. The monocline symmetry of the axes distribution is delineated by a specular plane lying perpendicular to the rupture plane and separates the axes into two groups: S and Z. The synoptic vector of displacement of the hanging limb is the intersection line of the symmetry plane and the fault zone plane. The thereby derived synoptic vector indicates a mean direction of displacement in the rupture zone. The synoptic inner axis of rotation lies in the plane of this rupture and is normal to the symmetry plane, and the specific axes of rotation are distributed around the synoptic axis. More detailed methods of determination of the position of the specular plane and the orientations of the displacement

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**Fig. 3** Vatapvayam dome.

1-4 – neoautochthon: 1 – Quaternary alluvium, 2 – Miocene-Pliocene subaerial volcanics, 3 – Middle Eocene, Snatol suite: shelf sediments, 4 – Miocene granodiorites; 5-9 – allochthonous complex: 5, 6 – Campanian-Maastrichtian, Iruneiskiy suite: tuffs, cherts: 5 – upper subsuite: tuffs, cherts; 6 – lower subsuite: pillow basalts; 7 – green schists and quartzites, 8 – gabbroides, 9 – peridotites; 10 – autochthon: Upper Cretaceous, Lesnaya Group, terrigenous flysch; 11 – Lesnaya thrust; 12 – other thrusts; 13 – ruptures with high-angle slip plane; 14 – cleavage orientation.

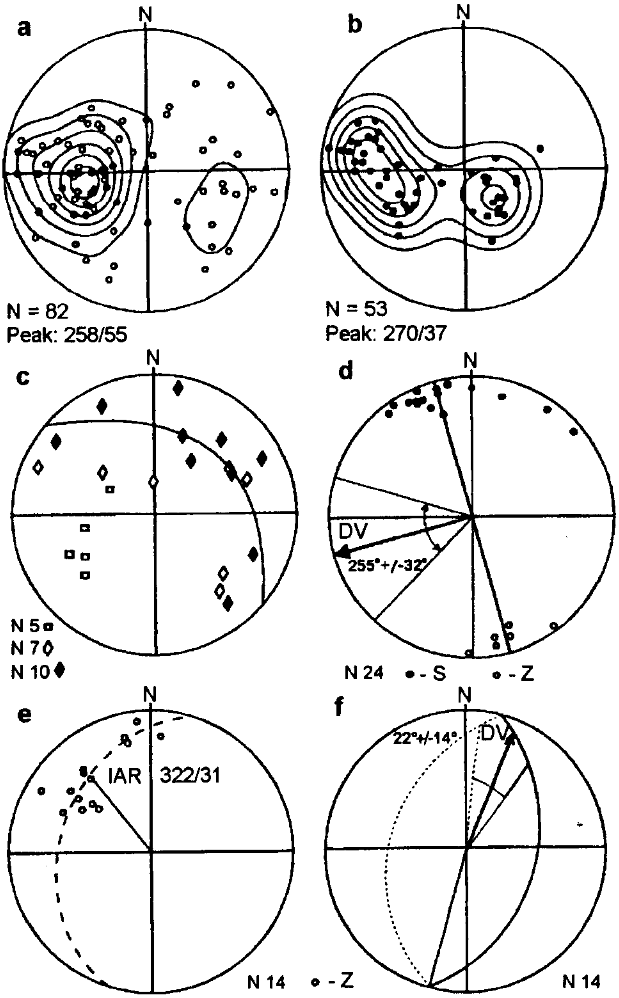

**Fig. 4** Diagrams of structural investigations within Vatapvayam dome.

On all diagrams (except " f ") projections of structural elements are shown on the lower hemisphere (Schmidt net). N – number of structural elements used in calculations.

**a** – diagram of poles of layering of Lesnaya Group deposits (normal and overturned occurrences are not separated); **b** – diagram of poles of cleavage in deposits of Lesnaya Group; c - diagram of poles of axial planes (open squares) and fold bends (black rhombs – measurements in exposures, open rhombs – computed) in deposits of Lesnaya Group; d – kinematic diagram of asymmetric folds in cherty-quartzite unit, black circles – fold axes with S-asymmetry, open circles – fold axes with Z-asymmetry, DV – reconstructed displacement vector, an arc indicates confidence angle; e – kinematic diagram of inner axes of rotation (IAR) for Riedel structures in the zone of Lesnaya thrust, numerical value – "average" axis, dash arc of greater circle corresponds to "average" surface of thrust at observation station; f – kinematic diagram of orientation of synoptical displacement vector (DV) in the plane of Lesnaya thrust (solid arc of greater circle – projection on the upper hemisphere, dash arc – projection on the lower hemisphere), arc (DV) shows confidence angle.

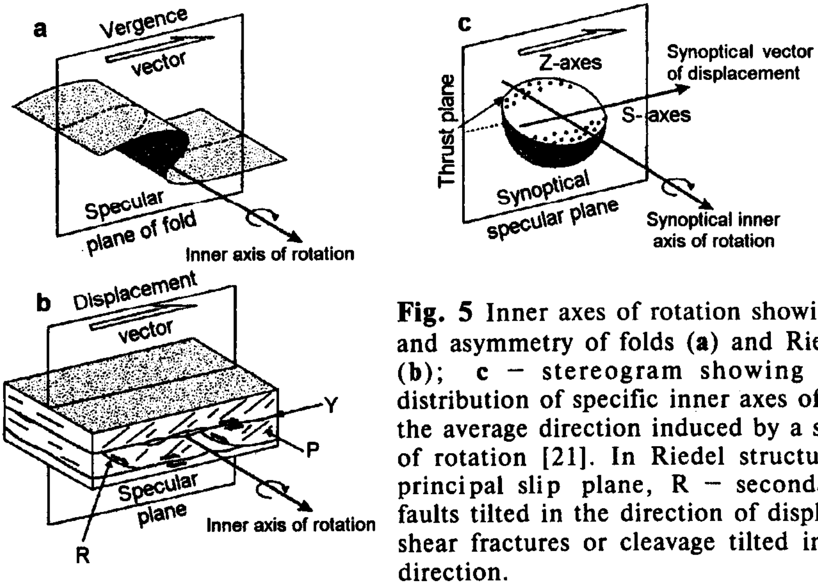

**Fig. 5** Inner axes of rotation showing orientation and asymmetry of folds (**a**) and Riedel structures (**b**); **c** – stereogram showing hypothetical distribution of specific inner axes of rotation near the average direction induced by a synoptical axis of rotation [21]. In Riedel structures; (**b**): Y – principal slip plane, R – secondary feathering faults tilted in the direction of displacement, P – shear fractures or cleavage tilted in the opposite direction.

vector both in the modern coordinates and in the thrust plane, and also statistical estimates of the derived directions were thoroughly tackled in [21].

## THE STRUCTURE OF VATAPVAYAM DOME

### Autochthon

The Lesnaya Group making up the autochthon is a terrigenous flyschoid ubiquitously strongly deformed, and crumpled into small folds, often with a well-developed cleavage. The bed orientations in the most exposed, southern part of the Vatapvayam dome have a highly wide range; incidentally a slight predominance of E-dipping bedding is demonstrated, which is indicative of prevailing development of folds overturned to the west (Fig. 4a). The axial planes of four folds studied in the northern part of the dome dip to the northeast (subparallel to the local strike of the slip plane of the Lesnaya thrust); and of one fold, to the southeast (Fig. 4c). The measured in exposures and computed orientations of the bends of folds from the northern part of the dome have a rather wide spread, apparently, grouping around the arc of a great circle tilted to the northeast, subparallel to the northeastern flank of the dome. Incidentally, two groups of these folds can be outlined: with subhorizontal bends plunging to the northwest and southeast, and with high-angle bends plunging to the northeast, which suggests movements of both perpendicular (in plan) to the local strike of the thrust (WSW-ENE), and parallel to it; though there are solitary measurements of folds also of other orientations.

Cleavage in the rocks of the Lesnaya Group in the southern part of the Vatapvayam dome seems to be more ordered and has principally asubmeridional strike (Fig. 3, 4b). In the eastern and central parts of the dome the cleavage planes are tilted mainly to the east at angles of 20 to 80°. The western part of the dome shows a predominance of low-angle (20-35°) tilting to the northwest. Horizontal orientations of cleavage are observed at the boundary of these two domains.

## Zone of the Lesnaya thrust

The main features of the slip plane of the Lesnaya thrust were described by A.Ye. Shantser *et al.* [18]. An inconstant, in terms of thickness (a few meters to a few hundreds of meters), zone of sedimentary melange, breccias and mylonites stretches along the boundary of the Lesnaya and Iruneiskiy suites from the source of the Pustaya River on the northeast as far as the Palana River basin on the southwest. This zone is well exposed on the flanks of the Vatapvayam dome: a high-angle western and a gentle southeastern flank. At some places of the eastern flank it is clearly discernible that the slip plane is discordant with respect to structures of the autochthon and allochthon (Fig. 6).

The inner structure of the Lesnaya thrust on the western flank of the dome is well observable in the upper reaches of the Gnunvayam River (right tributary of the Palana River) (Fig. 7). The slip plane of the thrust and beds in the autochthon and allochthon have a nearly identical orientation: they are WNW-dipping (280-330°) at an angle of 40 to 60°. Beneath the thrust in a zone about 150-200 m thick the Lesnaya Group grades out into a megabreccia, where bed fragments generally retain northwestern dips but do not stretch for more than 0.2-0.5 m. Relatively isometric blocks of dark-gray andesite dacite tuffs and black glassy cherts are sunk into this matrix; sometimes they form homogeneous breccias from cherty fragments in the tuff cement, and occasionally, an alternation of thick and indistinctly bounded beds. These blocks measure 50-70 m, but blocks up to 10 m across are more frequent. At the contact of these blocks and the enclosing flysch gliding planes are observed. Such "exotic" blocks are widely known in the under-thrust zone of the Lesnaya uplift. Psephitic tuffs with fragments of inoceram shells, gray and red cherts, and also highly titaniferous aphyric pillow basalts were detected earlier in their composition [20]. Immediately beneath the thrust, in a zone 20-25 m thick the breccia matrix loses indications of stratification, and the bulk of fragments of sandy layers acquire an isometric configuration. This zone is characterized by nearly spherical blocks of massive intermediate- and coarse-grained sandstone measuring up to 2-3 m, though generally thick interlayers of massive sandstone are not common in the Lesnaya Group.

Structurally higher begins a zone of "variegated mylonites", in which alternate thin (1-10 mm) lenses-bands of dark-gray and black material, which,

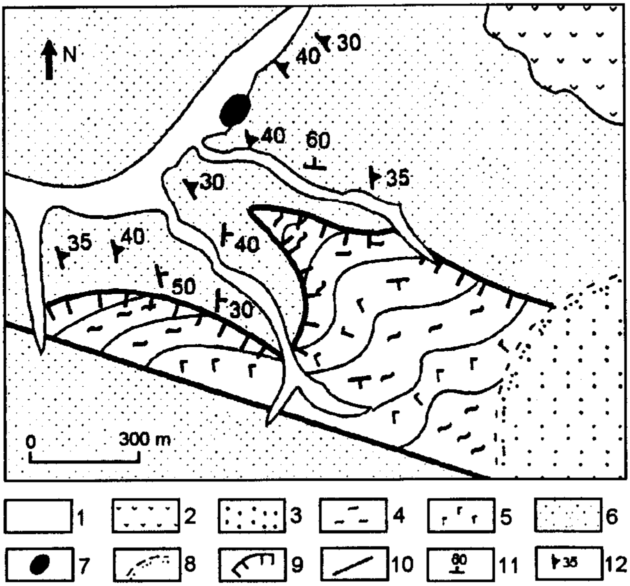

**Fig. 6** Structure of the zone of Lesnaya thrust in the upper reaches of the right tributary of Vatapvayam River.

1-3 – neoautochthon: 1 – Quaternary alluvium, 2 – Miocene-Pliocene volcanics, 3 – Snatol suite (mid-Eocene): sandstone; 4, 5 – allochthon: Iruneiskiy suite: 4 – tuff and chert, 5 – basalt; 6, 7 – autochthon: 6 – Lesnaya Group, 7 – large exotic block of pillow basalts; 8 – unconformity in the base of Snatol suite (inferred); 9 – Lesnaya thrust; 10 – normal fault; 11, 12 – strike and dip: 11 – of beds, 12 – of cleavage.

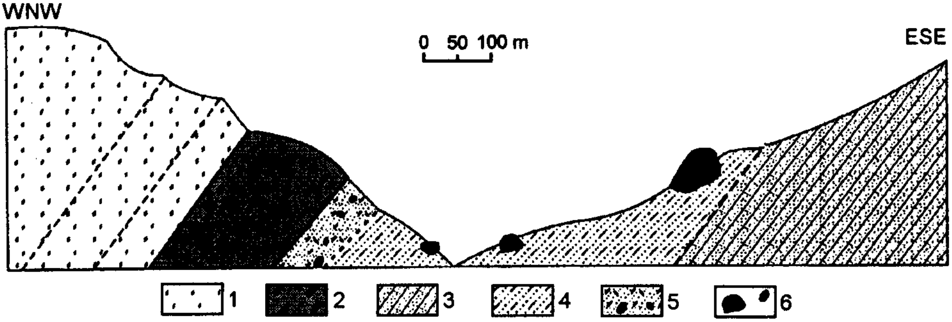

**Fig. 7** Structure of the zone of Lesnaya thrust in the upper reaches of Gnunvayam River.

1 – allochthon, Iruneiskiy suite; 2 – mylonite zone; 3-6 – autochthon, Lesnaya Group: 3 –weakly deformed flysch, 4 – zone with bed fragments retaining general strike, 5 – zone where bed fragments are chaotically oriented, 6 – exotic blocks of tuff, chert, and sandstone.

apparently, had its origin in the Lesnaya Group, and gray-green material related to tuff reworking of the Iruneiskiy suite.

Above the zone of "variegated mylonites" the Iruneiskiy suite begins outcropping; the suite is formed of alternation of fine-grained green tuffs and light greenish-gray cherts. At the first 100 m of this section the sheets and chert bands of low thickness are commonly boudinaged.

All elements of Riedel structures representing strike-slip zones 0.05 to 0.5 m thick and traced in the exposure at a distance of 0.5 to 20 m were observed in the "variegated mylonites". The fractures bounding these zones are subparallel to the general orientation of mylonites and are interpreted as Y planes. P cleavage is widely developed between them oblique-oriented with respect to Y planes. R fractures running across the cleavage are less frequent. The inner axes of rotation (intersection lines of the Y and P local planes) dip to the northwest or less frequently, to the north (Fig. 4e) and are indicative of clockwise rotation (Z-axes). In the modern coordinates the synoptical vector of displacement of the hanging limb computed according to the method in [21], is NNE-oriented (22°+/-14°) in the thrust plane.

## Allochthonous complex

The bulk of the allochthon of the Lesnaya uplift is built by the Iruneiskiy suite, which is described in a number of writings [2, 6]. On the west of the uplift it has a two-member structure with predominance of pillow basalts and jaspers in the lower part, and fine fragmental tuff and chert in the upper part, but immediately on the flanks of the Vatapvayam dome their relationships are not observable. Small (a few centimeters to a few meters) folds are not characteristic of the Iruneiskiy suite dominated by massive layered rocks, and folds with limbs of a few meters to a few tens of meters are quite rare. Large folds in the Iruneiskiy suite of northern Kamchatka are generally NE-striking, but near the Lesnaya thrust bedding in the Iruneiskiy suite is commonly close to the orientation of its slip plane with a high-angle western dip on the western flank of the Vatapvayam dome and a gentle dip to the southeast in the south of the eastern flank.

In the northern part the eastern flank of the Vatapvayam dome becomes steeper again. A thick sequence of green schists and quartzites with banding and schistosity, principally parallel to the slip plane of the Lesnaya thrust, appears in the base of the allochthon, structurally lower than the common tuff and chert of the Iruneiskiy suite. The contact of this thick sequence with the Iruneiskiy suite is tectonic. Most schists have quartz-albite-epidote-chlorite-sericitic composition; rocks holding actinolite are frequent, and garnet-bearing rocks are rare. Schist fragments often show very small tight folds with their axial planes parallel to schistosity; however, no such structures have been detected in bedrock exposures. The protolith of schists and quartzites was a layered tufogenic-siliceous thick sequence compositionally close to the Iruneiskiy suite and including horizons of red chert that are characteristic of this suite and that retained their coloring even when became transformed into quartzites. Increasing in thickness, the schist-quartzite unit is traced along th Lesnaya thrust more to the north, on the right bank of the Levaya Lesnaya River, and then in the upper reaches of the Tklevayam River (see Fig. 3). North of the Vatapvayam dome outcrops of the schist-quartzite unit are registered at a distance over 3 km and then are changed by the outcrop of the Iruneiskiy suite. Immediately north of the study region, in the basin of the Gnunuguvayam River, in the area of development of the Iruneiskiy suite dragfolded tuff and silicified chert are frequent, structurally and compositionally close to schists and quartzites occurring on the northeastern flank of the Vatapvayam dome. At the same time, gradual transitions from schists to nonmetamorphosed tuffs were not observed directly in the exposures.

Medium- and fine-grained amphibolized gabbro, rare pyroxenites and small bodies of micaceous peridotites occur in the upper reaches of the Tklevayam River, structurally below the schist thick sequence. Xenoliths of hornfels replacing layered rocks with banding orientation not coinciding with banding orientation in the intrusive matrix were repeatedly described in the gabbroides. The lower contact of the gabbroides is tectonic. The gabbroid occurrence on the Lesnaya Group is well discernible in the watershed of the Lekhai-Gigivayam and Tklevayam Rivers (Fig. 8). A megabreccia with blocks of chert and basalt tuffs in a matrix of deformed mud- and sandstone is developed there below the nearly horizontal slip plane of the thrust and poorly exposed mylonites of low thickness. On the right bank of the Tklevayam River the contact between the gabbroides and overlying metamorphic schists is well pronounced (Fig. 9). The contact zone 7-8 to 20-30 m thick shows a transition from the foliated gabbro through the banded amphiboles and thin-banded blastomylonites, in which small bands of amphibolite and quartz-albite-chlorite composition alternate, to the above-lying schists. Some of the amphibolite bands hold fine garnet. In all likelihood, this is a synmetamorphic tectonic contact. Banding in the zone of this contact is tilted to the northeast at angles of 15-45°. There are indications that the metamorphic schists and tuffs of the Iruneiskiy suite are underlain by ultrabasite-gabbro bodies over the entire interfluve of the Tklevayam and Gnunuguvayam Rivers, since in the near-channel parts of the Vaichech-Ainenvayam and Gnunuguvayam Rivers gabbro-ultrabasite bodies crosscutting the general tectonic structure and bounded by vertical faults are described; these bodies are represented by modern positive structures and morphlogically resemble protrusions.

In the western part of the Tklevayam and Vaichech-Ainenvayam watershed there occurs a thick sequence of pillow aphyric and plagiophyric basalts steeply dipping to the east and characterized by an overturned position; this unit is

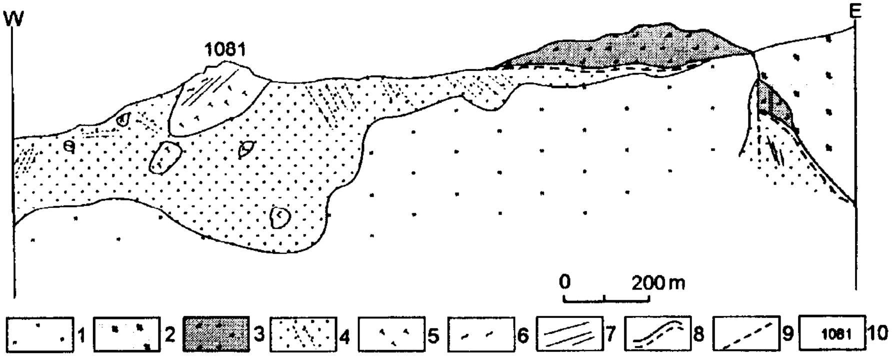

**Fig. 8** Structure of the zone of Lesnaya thrust in the Lekhai-Gitgivayam and Tklevayam watershed (drawing of exposure).

1 – hillslide and turf-covered slopes; 2,3 – allochthon: 2 – green schists, 3 – amphibolized gabbro; 4-7 – autochthon: 4 – Lesnaya Group with discernible strike of beds; 5-7 – exotic blocks: 5 – of tuff, 6 – of mudstone, 7 – of black chert; 8 – Lesnaya thrust; 9 – other ruptures; 10 – topography marks.

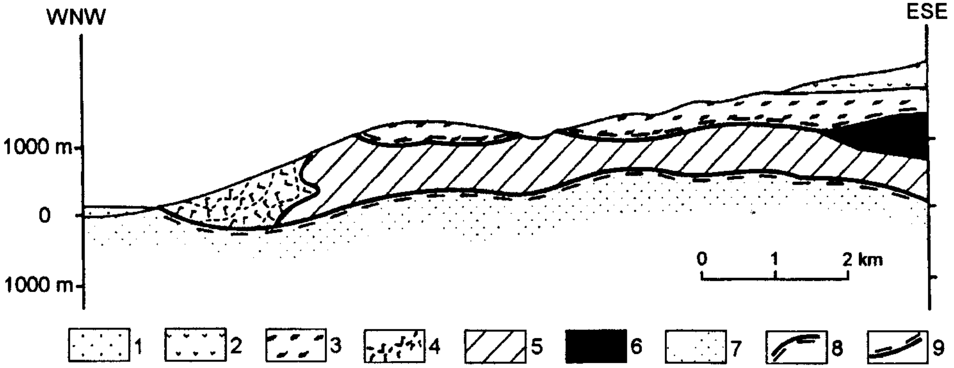

**Fig. 9** Profile through the Tklevayam and Vaichech-Ainenvayam watershed.

1 – Quaternary alluvium; 2 – Mio-Pliocene volcanics; 3- green schists; 4 – basalts of lower subsuite of Iruneiskiy suite; 5 – gabbroides; 6 – peridotites; 7 – Lesnaya Group; 8 – Lesnaya thrust; 9 – thrust in the base of a schist unit.

hypsometrically subjacent with respect to the gabbroides. Compositionally close units located more to the north, in the basins of the Pravaya Lesnaya, Shamanka, and Eningvayam Rivers were described in the lower part of the Iruneiskiy suite. Despite a relatively good exposure of the contact zone of gabbroides and basalts in the watershed part of the range, it is not easy to define the exact position of the contact, since part of the gabbroid massif, the closest to the basalts, is made up of fine-grained diabases compositionally

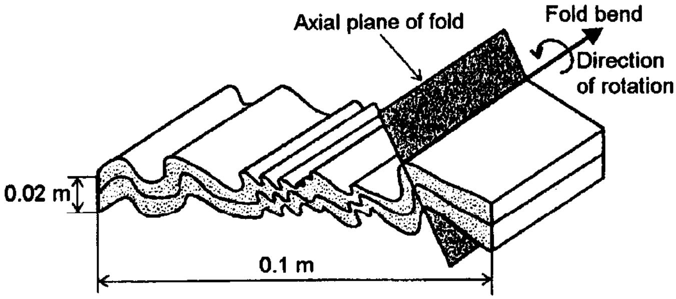

**Fig. 10** Morphology of small folds in blastomylonites at the boundary of quartzite-schist complex and gabbroid plate.

close to the basalts proper, and the basalts in most cases are represented by well crystallized aphyric massive varieties and are distinguished primarily by pillow-like jointing, which is not always observable. Anyway, the gabbro is not separated from the basalts by a marked tectonic zone or a basal horizon, and most likely has an intrusive contact with them. Hypsometrically below the basalts in the channels of the Tklevayam and Vaichech-Ainenvayam Rivers the Lesnaya Group outcrops, but the slip plane of the Lesnaya thrust is not exposed there.

At the boundary of gabbroides and schists, in the blastomylonite zone and in the lower part of the schist unit proper numerous small asymmetric folds were observed whose subhorizontal bends have a submeridional strike (Fig. 10). The schistosity plane often shows striation parallel to these fold bends and caused by a wide development of microfolds with the same orientation. The fold axes tilted to the north indicate counterclockwise rotation (S-axes), and tilted to the south, clockwise rotation (Z-axes). This means that movement of the upper plate (schists) relative to the lower plate (gabbroides) occurred in the western direction. The computed synoptical vector of displacement is W-SW-oriented (255°±32°) (see Fig. 4d).

## DISCUSSION

Two substantial thrusts are observed on the northeastern flank of the Vatapvayam dome: the Lesnaya thrust proper, on which an allochthonous complex comprising the Iruneiskiy suite, metamorphites and gabbroides is thrust onto the Lesnaya Group, and a thrust in the allochthonous complex, on which metamorphic schists contact gabbroides. We have no direct evidence of chronological relations of movements along these ruptures, and these relations demand discussion.

A major difficulty is dating of movements at the gabbro-metamorphite boundary, since there are no direct data on the age of these complexes, and their relations with the Iruneiskiy suite have not been reliably specified. We infer an intrusive contact of gabbroides with basalts assigned to the lower subsuite of the Iruneiskiy suite. If this assumption is correct, then the ultrabasite-gabbro complex cannot be older than Campanian. This conclusion is supported by correlation of gabbro and ultrabasites of the Lesnaya uplift with more thoroughly studied and large Late Cretaceous gabbro-ultrabasite intrusions confined to other sites of the Vatyna-Andrianovka suture. For example, B.A. Markovskiy [2], basing on petrographic similarity, assigns the gabbro and ultrabasites of the Lesnaya uplift to the Levoandrianovka intrusive complex distinguished on the eastern slopes of the southern part of the Sredinnyi Range. The intrusions there are dated as the end of the Cretaceous-beginning of the Paleogene [16]. Large gabbro-ultrabasite intrusions of close composition are confined to the hanging wall of the Vatyna-Vyvenka thrust in the Olyutorka zone. There are data on the genetic and chronological affinity between these intrusions and the upper (Maastrichtian-Danian) volcanogenic complexes of the allochthon [1]. Proceeding from these correlations, the most probable age of intrusion of the study gabbroides is Maastrichtian-Danian.

Correlation with other parts of the region virtually yields no positive results for assessment of the age of metamorphites of the quartzite-schist thick sequence. In the Olyutorka zone metamorphic complexes in the base of the Cretaceous allochthon are absent. In the south of the Sredinnyi Range of Kamchatka, on the contrary, they are widely developed, but there are alternative interpretations concerning both the age of the protolith and the age of metamorphism. In these conditions the general lithological similarity between the metamorphic rocks of the Lesnaya uplift and the Iruneiskiy suite, and alternating schistose and non-schistose tuffs in the Iruneiskiy suite north of the Vatapvayam dome remain the only criteria allowing the assumption that the quartzite-schist unit is a metamorphosed analog of the Iruneiskiy suite. Proceeding from the structure of the non-metamorphosed sections of this suite, the observed schists formed most likely at the expense of the middle part of its section of Campanian-Maastrichtian age. Metamorphism of these rocks is apparently dated as the very end of the Cretaceous-beginning of the Paleogene. Thus, the most probable intervals of schist metamorphism and injection of ultrabasite-gabbro intrusions are almost similar.

Morphologically and kinematically the tectonic break at the boundary of gabbroides and metamorphism is a thrust with movement of the hanging wall to the west relative to the lying wall. Thrusting was operative in conditions of elevated temperatures and pressure with formation of blastomylonites and transformation of the upper part of the gabbroid massif into banded amphibolites. However, this metamorphism slackens rapidly downward from the thrust, and the bulk of the gabbroides experience only amphibolization without any substantial structural alterations. Basalts intruded (?) by gabbroides are not metamorphosed either. Thus, it is a local zone of dynamothermal metamorphism with respect to gabbroides. The nature of metamorphism of the schist is not specified. Judging by its wide distribution and great thickness, it is regional metamorphism unrelated directly to the thrust along which metamorphic and intrusive rocks are only in contact. However, it is not impossible that metamorphism is linked to thrusting of the non-metamorphosed Iruneiskiy rocks on a large massif of still warm gabbro and ultrabasites, which was a heat source. In the latter case thrusting was close in time to the origin of the gabbro-ultrabasite complex at the very close of the Cretaceous. If schists are products of regional metamorphism, then thrusting could occur considerably later – in the Paleocene or even at the beginning of the Eocene.

Overthrusting of the intensely deformed allochthonous complex on the Lesnaya autochthon occurred in the interval between the end of the Maastrichtian (the most probable age of the upper horizons of the Lesnaya Group and Iruneiskiy suite) and middle of the Eocene (upper age limit of the base of the neoautochthonous Kinkil suite). Therefore, the intervals of possible movements on the Lesnaya thrust and a thrust within the allochthonous complex are overlapped. However, neocrystallization in the rocks of the Lesnaya suite and in mylonites at its boundary with the allochthon has a low temperature character, and metamorphism there is not so deep-seated as at the boundary of the above-lying gabbroides and schists. It follows that movements at the boundary of the gabbroid and metamorphic complexes that were operative at a deeper level had ended before these complexes were moved onto the surface at the final stage of overthrusting.

The problem of the direction of movement on the main slip plane of the Lesnaya thrust proved highly complicated. On the one hand, this thrust stretches to the northeast along the Kamchatka isthmus for 150 km. Its continuation, Vyvenka thrust in the Koryk Highland, stretches for another 400 km [1, 3, 11, 13]. The directly observed overlapping (transverse with respect to the suture) of autochthonous flysch units by the allochthon reaches a few tens of kilometers. It is commonly presumed that such a substantial overlap should principally require the movement of the allochthon in the direction transverse with respect to the general strike of the collision suture, i.e., from southeast to northwest. Normally also deformation of plastic sedimentary units of the autochthon is linked to such movement of allochthonous masses and compression perpendicular to the collision suture.

However, not all the features of the structure of the autochthon and slip plane of the Lesnaya thrust accord with this simple pattern. In mylonites developed along the slip plane of the Lesnaya thrust direct kinematic indicators – Riedel structures – point to the movement of the allochthonous complex to the north-northeast, along the regional strike of the thrust line. This is in agreement with data obtained on the north, in the Olyutorka zone, in the southern part of the Vatyna-Vyvenka thrust [13, 14]. Movements parallel to the thrust front could also result in folds with subhorizontal bends in the Lesnaya Group on the north of the Vatapvayam dome (Fig. 4c). The other part of folds developed there (with high-angle bends), probably, formed as a result of movements on strike-slip faults, perpendicular to the thrust front. However, both these systems of folds formed under compression parallel to the general strike of the front of the Lesnaya thrust (SW-NE). In the southern part of the Vatapvayam dome layering of the autochthon is oriented almost chaotically, and only statistical analysis allows a suggestion of a slight predominance of submeridional folds overturned to the east. Cleavage is more ordered there, which strikes submeridionally and is indicative of deformation under conditions of sublatitudinal compression. However, cleavage orientations also have a peculiarity demanding clarification: contrary tilts of cleavage on the western and eastern flanks of the Vatapvayam dome. If we assume that most of the measured planes correspond to the cleavage of the axial plane in the system of submeridional folds, then we should either conclude that the vergence of folds in different part of the autochthon can be opposite in direction or presume a strong bend of the roof of the autochthon in the course of growth of the Vatapvayam dome. Incidentally, cleavage planes initially tilted mainly to the east, did not change the direction on the eastern flank of the dome but became steeper, and on the western flank they tilted gently in the opposite direction.

Apparently, the fold structure of the autochthon is distinguished by complexity reflecting, on the one hand, inhomogeneity of the stress field in the plastic flysch unit, and on the other, superposition of several stages of deformation, which could be operative for a very long time, having started prior to collision of an island arc with the Eurasian margin reaching the maximal intensity during this collision and proceeding after its termination. Hence, the kinematics of formation of separate folds in the autochthon can have no direct connection with the direction of displacement of allochthonous masses. It is only statistical analysis that can help specifying the most stable peculiarities of the geometry of fold structures in the Lesnaya suite.

A certain autonomous character of movements in the plastic autochthon, their relative independence from the allochthon movements can be reflected also in the kinematics of a strike-slip fault at the boundary of the autochthonous and allochthonous complexes. This implies one of possible explanations of peculiar orientations of Riedel structures in mylonites of the Lesnaya thrust. We should not neglect the fact that these structures are indicators of relative movements, and that the immovability of the autochthon is only a condition accepted for convenience of analysis. At the same time, it should be again emphasized that the analysis of these structures at three substantially distant from each other sites of the Lesnaya and Vyvenka-Vatyna thrusts yielded one and the same result: displacement of the allochthonous complex relative to the autochthon proved to be NE-directed [13]. If it is a mere coincidence, then it implies that at a certain, most likely, last stage of collision between the Achaivayam-Balagina arc with Eurasia the arc experienced a sinistral strike slip along the tectonic suture.

Thus, we can outline several successive stages in the origin of the contemporary structure of the collision suture separating on the Kamchatka isthmus complexes of a Late Cretaceous island arc from coeval complexes of the continental margin, and the chronology of these stages requires additional investigation. The first movements are registered in the allochthonous complex of the Lesnaya thrust, when under relatively deep and high temperature conditions a quartzite-schist complex is thrust on an ultrabasite-gabbro massif intruding the lower horizons of the Iruneiskiy suite. Possibly, the formation of this rupture is not related to collision and it occurred in the base of an active arc on its way to the continent. It is only at the next stage – formation of the Lesnaya thrust proper – that these complexes are moved onto the surface, and together with the shallower parts of the allochthon are shifted to the northwest overlapping the folded terrigenous thick sequences of the Lesnaya Group. At the late stages of collision the conditions of frontal thrusting are apparently changed by the formation of transpressure structures and movement of the island arc complex to the northeast along the continental margin. Such kinematics was most likely conditioned by the direction of the motion of the Pacific plate relative to Eurasia [22]. The origin of the Aleutian arc and a strong change in the drift of the Pacific plate in the middle of the Eocene resulted in the termination of collision, but deformation of the slip plane of the Lesnaya thrust and plastic flysch autochthon proceeded even later, till the close of the Miocene.

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