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GEOLOGY

Deformations in Tertiary Complexes of Western Kamchatka (Tochilo Section)

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The eastern part of the Sea of Okhotsk and the western Kamchatka Peninsula are occupied by the Western Kamchatka Trough filled with Cenozoic sediments [1]. Its basement is composed of Jurassic–Cretaceous volcanogenic–terrigenous rocks characterized by a fold–thrust structure [2–4]. The western part of the Kamchatka Peninsula is poorly exposed; therefore, study of the coastal cliffs is of key importance for understanding of the structure of Tertiary complexes, which is, in turn, significant for interpretation of geodynamics of the northeastern Sea of Okhotsk and Kamchatka Peninsula region and reliable assessment of its petroleum resource potential.

The Tochilo section is located in western Kamchatka, where it is represented by outcrops of rocks, which constitute cliffs between the Amanina (in the south) and Etolona (in the north) rivers (Fig. 1). The height of cliffs varies from a few meters to 200 m, and they are approximately 50 km long. The Tochilo section is a unique geological object completely exposed and suitable for study of Tertiary complexes in western Kamchatka. Inasmuch as the cliffs are practically vertical, only their lower parts are accessible for immediate observations. Study of the structure is also complicated by landslides.

Remote methods of two types were used for more complete description of the coastal outcrops: on-land photography from the beach and a prospecting survey from a helicopter flying along the cliff. Each of these methods is characterized by advantages and disadvantages. Both of them substantially depend on the direction of the object illuminance. Due to the northern–northwestern strike of the cliff, sufficient illumination in sunny weather (relatively rare) is possible only during evening hours, when the sun is located in the west. The width of the beach varies from several to hundreds of meters depending on the tide height, which limits the possibilities of on-land photography. The helicopter-based photography is complicated by vibration and continually changeable distances and angles of view. Over 500 on-land images of the Tochilo section were obtained for investigation of its deformations. In addition, it was photographed using the digital photocamera Nikon D 70 from the helicopter, which provided over 400 images. The latter were subsequently combined into a single panorama using the Adobe Photoshop program.

The previous geological mapping revealed that Cenozoic sequences of the Western Kamchatka Trough are deformed into simple folds with NNW-trending axes [5–9]. It is believed [10] that Tertiary sediments fill grabens and rest upon the uneven surface of the intensely deformed pre-Cenozoic basement. Some authors emphasize the significant role of fractures and fold–block structure of western Kamchatka [10, 11], as well as the existence of elevated stable blocks in the Cenozoic against the background of general downwarping [10, 12].

Based on structural patterns, three areas are defined in western Kamchatka [10, 11]: southern, central, and northern. The first of them extends from the southern extremity of the Kamchatka Peninsula to 54° N and is characterized by wide synclinal near-meridional troughs (for example, the Icha Trough), which were formed under conditions of prolonged subsidence with compensated sedimentation. The area between 54 and 59° N is characterized by development of meridional synclinal and anticlinal folds, which are conjugate along faults. The important structure-forming role is thought to belong to gravitational tectogenesis [11, 13]. The northern area located north of 59° N is structurally similar to the southern one [11].

It is considered that the central part of western Kamchatka comprises "several different-size anticlinal and synclinal structures (some of them resemble horsts and grabens, respectively), which are traceable from the western coast of Kamchatka to Shelikhova

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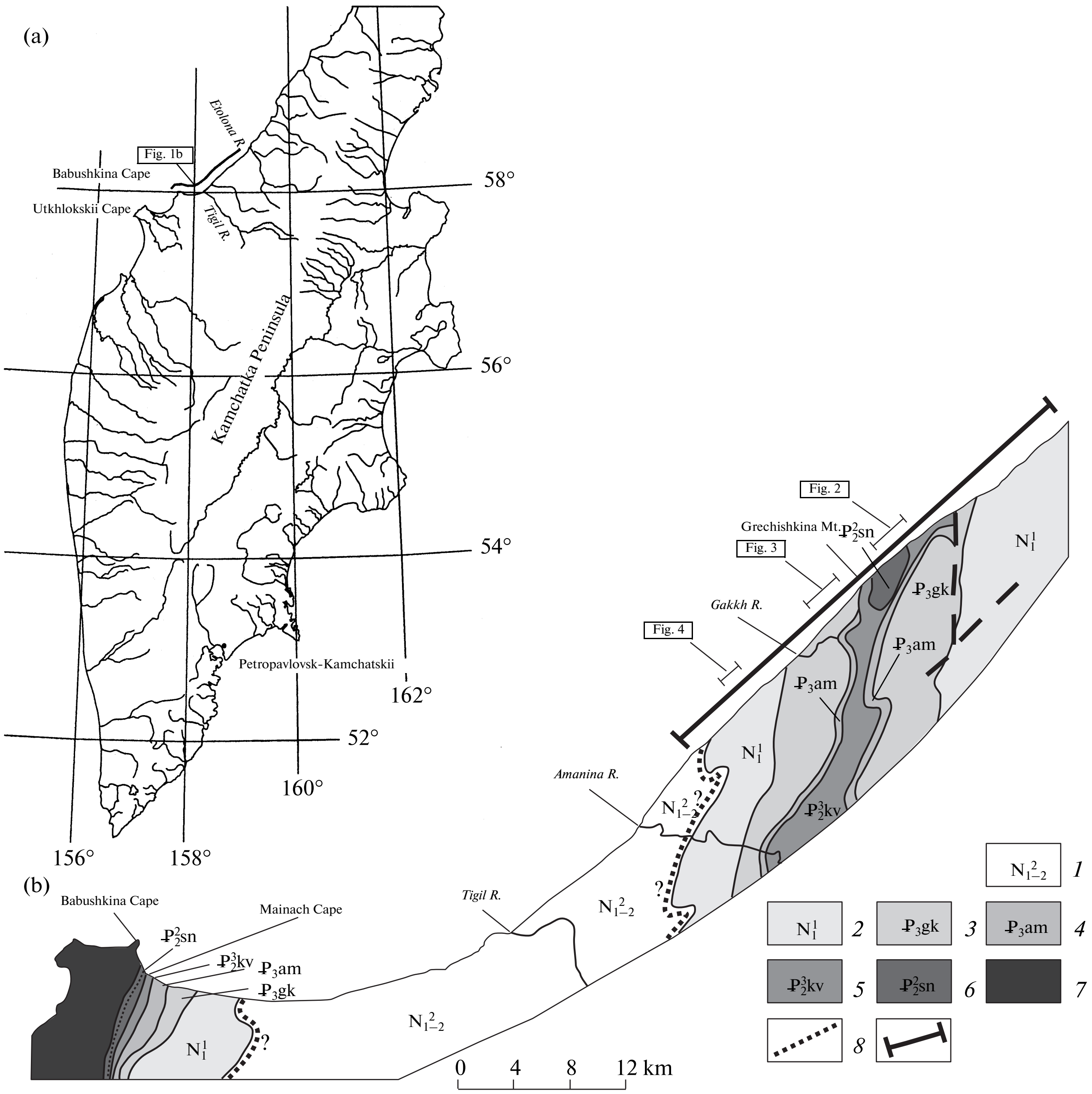

Fig. 1. Schematic geographic map of the Kamchatka Peninsula (a) shown study areas and schematic geological map of the Tigil area, after [7, modified]. (b): (*1–6*) sediments: (*1*) Upper Miocene–Pliocene, undivided (Il'inskaya, Kakert, Etolona, Erman, and Enemten formations), (*2*) Lower Miocene, undivided (Kuluven Formation), (*3*) Oligocene (Utkholok and Gakkh formations), (*4*) Oligocene (Amanina Formation), (*5*) Upper Eocene (Kovachina Formation), (*6*) Middle Eocene (Snatol Formation); (*7*) Mesozoic complexes; (*8*) angular unconformity at the base of the Il'inskaya Formation; (*9*) location of the Tochilo section.

Bay" [14, p. 8]. A remarkable structure among them is the Tochilo anticline, which is described thoroughly in [14, 15] and presented in geological maps, including a recent version in [9]. As was mentioned [13–15], the sediments are deformed, although insignificantly. At the same time, it should be noted that strongly deformed layers were shown in geological sections both north and south of the Gakkh River mouth (e.g., [13, Fig. 6]).

Thus, it is anonymously accepted that the Western Kamchatka Trough represents, with regard to its structure, a system of conjugate simple folds with NNW-oriented axes. The folds are complicated by steep faults.

We examined the Tochilo section during field works in 2003, 2006, and 2008.

The *core of the Tochilo anticline* is located north of the Gakkh River (Fig. 1), where it is composed of the

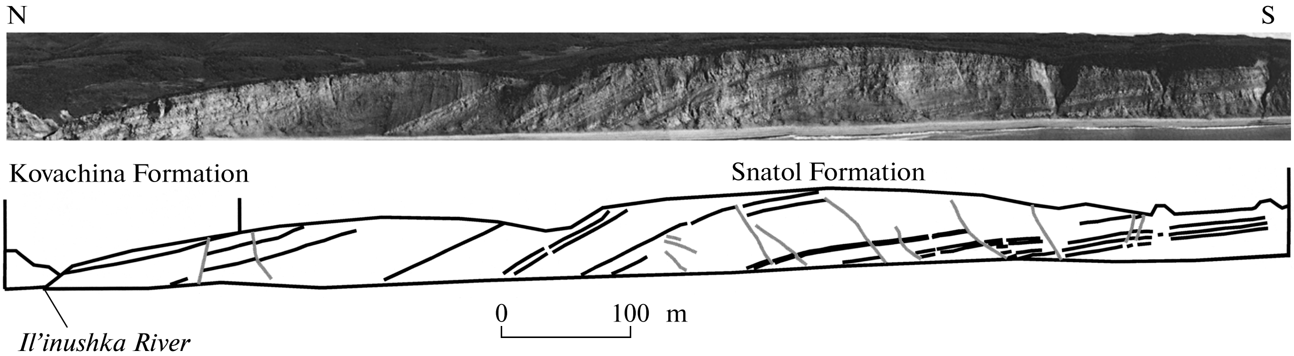

Fig. 2. The structure of the northern part of the Tochilo anticline core (for location, see Fig. 1). The upper part shows the photographic panorama and the lower part, its interpretation: black and gray lines designate marking layers and faults, respectively.

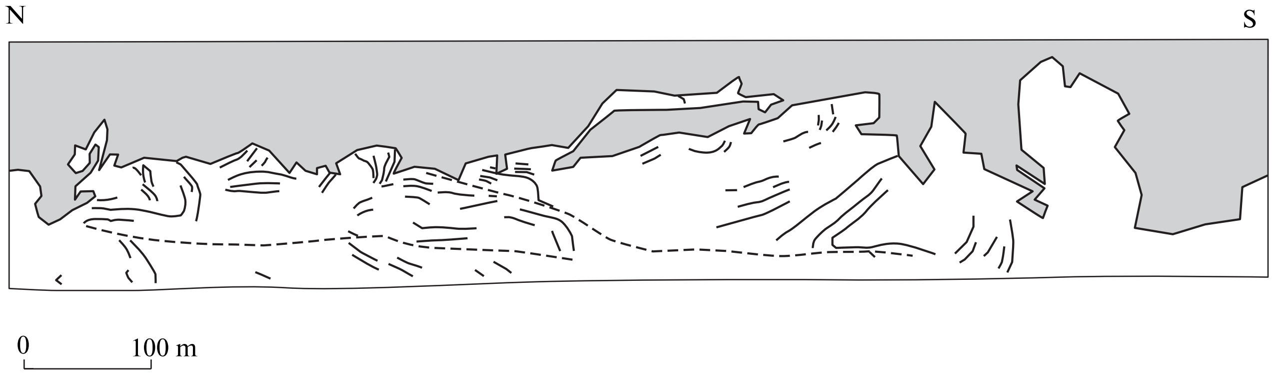

Fig. 3. The fold–thrust zone south of the Tochilo Creek (for location, see Fig. 1). Black and dotted lines designate reference layers and faults, respectively; gray color shows vegetation.

terrigenous Middle Eocene Snatol Formation; in the southern direction, dip angles increase from 15° to 35° (Fig. 2). The structure is complicated by southward inclined listric faults with amplitudes of a few meters. They control rockslides locally, which are responsible for the formation of peculiar relief forms such as landslide "cirques" and their triangular shape. The hinge of the fold is disturbed by a large landslide, which extends approximately for 2.5 km along the shore. The southern part of the landslide demonstrates deformed gray Snatol sandstones, which implies development of major fault zones that complicate the structure in the hinge part of the Tochilo antiform. Thus, the Tochilo anticline is characterized by an asymmetric structure with gentle northeastern and steep southwestern limbs. The hinge of the fold is complicated by fractures.

The outcrop located north of the conformable contact (azimuth and dip angles are 70° and 15°, respectively) between the Snatol and Kovachina strata (Il'inushka River mouth) is composed of alternating gray sandstones (similar to their counterparts in the Snatol Formation) and Kovachina siltstones, which implies development of "wedge-shaped pressing-in structures" along bedding surfaces in the Kovachina Formation.

The *northeastern limb of the Tochilo anticline* is perfectly exposed in sea cliffs between the Il'inushka and Etolona river mouths. It represents a slightly deformed homocline with dip angles in the Kovachina, Voyampol, and Kovrana groups increasing in the NNE direction from zero to 30° [14]. It is disturbed by low-amplitude (from a few meters to a few tens of meters) blind reversed faults with a northeastern dip of their planes and conjugate SW-dipping fractures with normal fault components.

The *southwestern limb of the Tochilo anticline* is characterized by a complex structure. South of its core, steep dip angles (approximately 60°) are retained at a distance of 300–400 m to become gentler toward the Tochilo Creek area marked by isolated folds. This segment of the limb is likely transitional to the zone of intense fold–thrust dislocations, which occupies approximately 800 m of the coastal cliff (Fig. 3).

In the southern limb, folding involved rocks of the Amanina Formation outcropping in the coastal cliff at a distance of approximately 750 m and constituting a homocline with steep dip angles of strata (the azimuth and dip angles are 300° and 70°–80°, respectively).

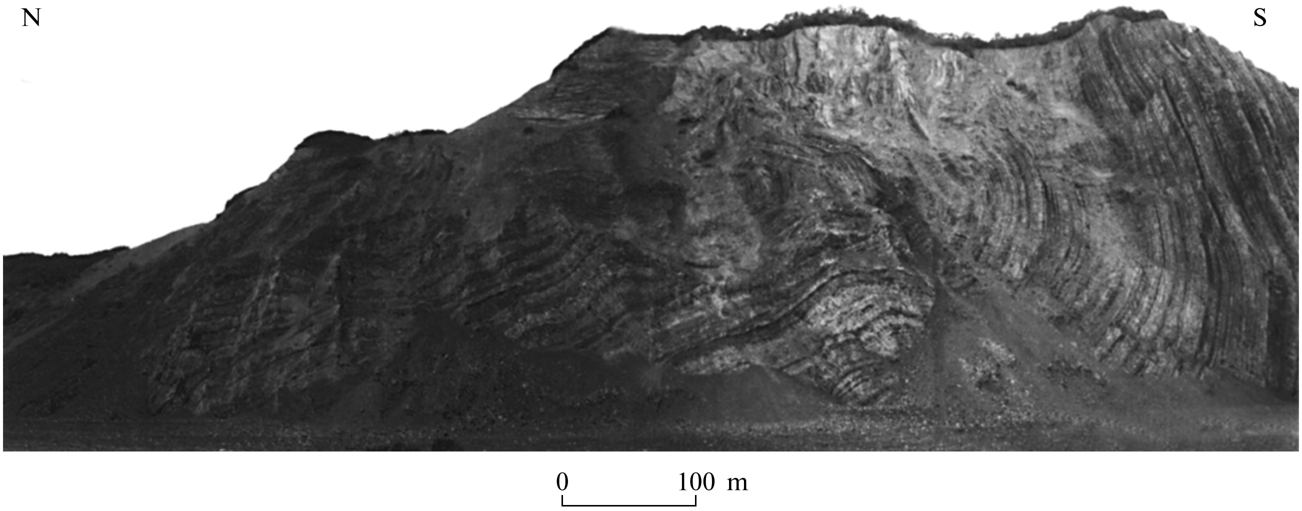

Fig. 4. The incumbent fold south of the Polovinnyi Creek (for location, see Fig. 1).

They are overlain by the Gakkh Formation with layers becoming gradually gentler (from 60° to 30°). A peculiar feature of the cliff segment under consideration is sharp bends of layers (of the kink-band type), folds with westward dipping hinges (declination and inclination are 220° and 5°, respectively). The deformation zone, which likely represents a duplex thrust, is approximately 800 m long.

The cliff segment located south of the Gakkh River is composed of the Gakkh, Utkholok, and Viventek formations. The first unit exposed at a distance of 1200 m forms a steeply dipping homocline (azimuth and dip angles are 295° and 65°–70°, respectively) complicated by numerous differently oriented low-amplitude faults. The upper part of the cliff is composed of intensely deformed rocks likely of the same age, which form a large recumbent fold. Its lower limb is truncated by a thrust.

In an area approximately 400 m long, which follows two large landslides to Polovinnyi Creek, layers of the Utkholok Formation are characterized by the reversed attitude (azimuth and dip angles are 300° and 60°, respectively). They form a homocline, which is locally disturbed by low-amplitude faults. South of Polovinnyi Creek, the homocline is subjected to intense disjunctive deformations with rocks being gradually transformed into tectonites. Further, at the distance of 300 m, the cliff is occupied by the recumbent fold (Fig. 4), which is complicated by a near-horizontal thrust. It is composed of the Voyampol Group with layers occurring almost vertically at the fold hinge (azimuth and dip angles are 100°–120° and 80°–85°, respectively) and grading southward into conjugate anti- and synclinal folds.

Away (1 km) from the Gakkh River mouth, deformed rocks of the Gakkh Formation are overlain with an angular unconformity by a terrigenous sequence structurally similar to the Upper Miocene Il'inskaya Formation, which is characterized by the near-horizontal occurrence of constituting beds.

Thus, the Tertiary sediments of western Kamchatka experienced significant fold–thrust deformations. The Oligocene–Lower Miocene sequences demonstrate isoclinal incumbent folds, thrusts, and duplex structures characteristic of the compression regime. The last stage of strong deformations occurred in the mid-Miocene and may represent a response to termination of collision between the Eastern Peninsulas (Kronotskaya) island arc and the eastern Kamchatka Peninsula.

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REFERENCES

1. *Geology of USSR. Vol. 31. Kamchatka, Kuril and Komandor Islands. Pt. I. Geological Description* (Nedra, Moscow, 1964), p. 734 [in Russian].
2. G. E. Bondarenko and V. A. Sokolov, Dokl. Akad. Nauk **315**, 1434–1437 (1990).
3. G. E. Bogdanov and V. A. Sokolkov, *Western Kamchatka: Geological Development in Mesozoic* (Nauch. mir, Moscow, 2005) [in Russian].
4. A. V. Solov'ev, *Study of Tectonic Processes in Regions of Lithospheric Plates Convergention. Methods of Track and*

Structural Analysis (Nauka, Moscow, 2008) [in Russian].

5. G. P. Singaevskii, *Geologic Map of USSR. Western Kamchatka Seria,* Sheet - 0-57-XXV (VSEGEI, Leningrad, 1965) [in Russian].
6. G. P. Singaevskii and D. A. Babushkin, *Geologic Map of USSR. Western Kamchatka Seria,* Sheets - 0-57-XX, XIX (VSEGEI, Leningrad, 1965) [in Russian].
7. P. A. Koval' and G. L. Aadmchuk, *Geologic Map of USSR. Western Kamchatka Seria,* Sheet - O-57-XV (VSEGEI, Leningrad, 1983) [in Russian].
8. *Geologic Map of USSR 1:1000000 (New Ser.). Sheet O-57, (58)—Palana,* Ed. by B. A. Markovskii, Explanatory Note (VSEGEI, Leningrad, 1989) [in Russian].
9. *Map of Mineral Resources of Kamchatka Region 1:500 000,* Ed. by A. F. Litvinov, M. G. Patok, and B. A. Markovskii (VSEGEI, Kamchatprirodresurs, St.-Petersburg, 1999) [in Russian].
10. *Explanatory Note to Tectonic Map of Okhotskoe Sea Region 1 : 2 50 000,* Ed. by N. A. Bogdanov and V. E. Khain (ILOVM RAN, Moscow, 2000) [in Russian].
11. L. M. Smirnov, Geotektonika, No. 3, 104–117 (1971).
12. V. P. Tuzov, L. I. Mitrofanova, R. V. Danchenko, et al., Stratigr. Geol. Korrelyatsiya **5** (3), 66–82 (1997) [Stratigr. Geol. Correlation **5**, 265 (1997)].
13. Yu. B. Gladenkov, V. N. Sinel'nikova, A. I. Chelebaeva, et al., *Biosphere-Ecosystem-Biota during the Earth's Past. Ecosystems in the Cenozoic of the Northern Pacific: Eocene-Oligocene of Western Kamchatka and Contiguous Regions* (Geos, Moscow, 2005) [in Russian].
14. Yu. B. Gladenkov, V. N. Sinel'nikova, A. E. Shantser, et al., *Eocene of Western Kamchatka* (Nauka, Moscow, 1991) [in Russian].
15. Yu. B. Gladenkov, A. E. Shantser, A. I. Chelebaeva, et al., *Lower Paleogene of Western Kamchatka (Stratigraphy, Paleogeography, Geological Events)* (Geos, Moscow, 1997) [in Russian].

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