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GEOLOGY

Exogenic and Neotectonic Processes in the West Spitsbergen Underwater Margin during the Late Cenozoic

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The purpose of this study is to define basic faults in the bottom topography of the West Spitsbergen underwater margin (Fig. 1) and estimate proportions between exogenic and endogenic processes in this region during the Quaternary. This work is based on the following materials of the Marine Arctic Geological Expedition: seismoacoustic time sections, a map of local topography, a map of tectonic deformations based on CMP data, a map of basement structural zoning, a neotectonic map, and a state geological map [1, 2].

The faults were defined on the map of local topography based on lineaments with maximal negative values. In most cases, the faults defined in such a manner coincided or were controlled by the CMP data. Hence, the Quaternary period was marked by the formation of new faults and the activation of older faults. Based on the analysis of all faults and the assumption that the direction of faults characterizes their geodynamic constraints, we defined the following main groups (Fig. 2).

The NW-trending faults parallel to the shoreline. In the bottom topography, these faults are represented by alternation of extended horsts and grabens with variable length and an asymmetrical profile reflected well in the basement.

Such faults are represented by the Forlandsun Graben, the zone of the outer shelf steps (the Knelegg–Hornsund and Prince Karl terraces), and the Atka Trough.

The *Prince Karl Horst.* In physical fields, this structure is represented by a zone of local NW-trending positive anomalies 15–20 km wide. It is a typical continental structure with the two-layer basement. The lower (Early Proterozoic) crystalline layer is located at depths of 2.5 to 5.0 km in the northwest and southeast, respectively. The upper layer is composed of deformed Riphean rocks that are known from Prince Karl Land and the western Spitsbergen coast. In the bottom topography, it is manifested either as elevated areas with bedrock outcrops subjected to glacier exaration or as quest ridges fringing the fjords.

The monocline of the Western Coast Horst is defined in the southeastern part of the study region.

The *Forlandsun Graben* begins in the synonymous strait and continues in the southeast direction as a 13- to 15-km-wide band at least up to the latitude of the Jan Mayen Fjord. In physical fields, it is represented by negative anomalies of the magnetic field and a vertical gradient of the gravity potential; i.e., we can see a direct correlation between the sign of the structure and anomalies of potential fields. The crystalline basement located at a depth of 7–8 km is overlain by 5-km-thick Riphean deformed sediments. The graben shoulders are complicated by subvertical normal faults. The western high-amplitude shoulder includes listric faults with the gliding plane inclined toward the platform.

A steep fault with planes inclined toward the trough depocenter complicates the near-continent wall and forms tectonic elements of the Prince Karl Horst and terraces of the uplift zone of the western coast. In the bottom topography, the horst is manifested as a chain of overdeepened depressions.

The *Hornsund Fault Zone* (amplitude of vertical displacements up to 1.5–2.0 s) is distinctly recorded in seismic sections. It should be noted that this zone is marked by maximal values of the horizontal gradient of the Bouguer anomaly (2.67 g/cm^3) and intense narrow

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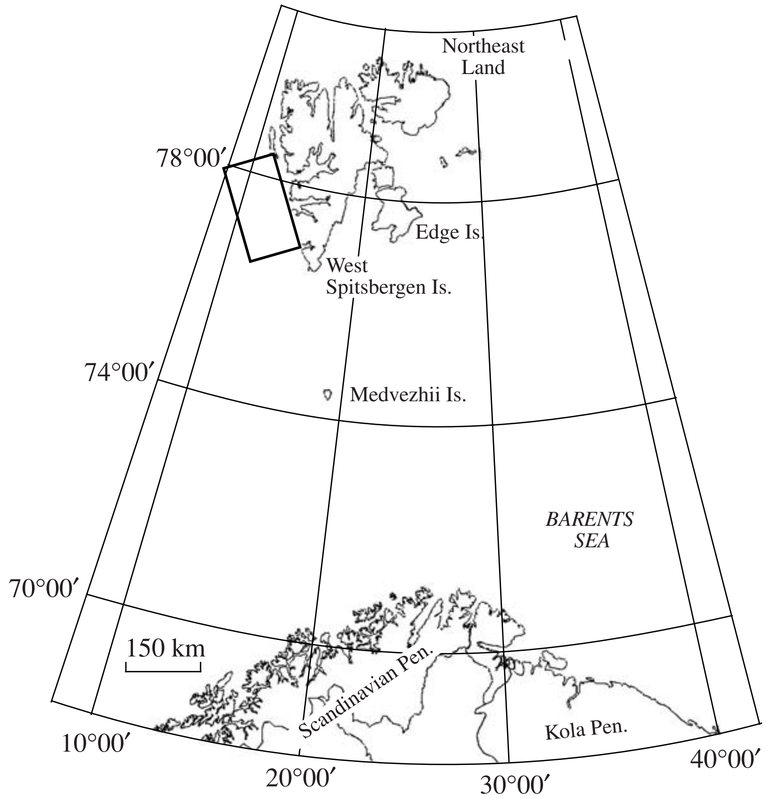

Fig. 1. Schematic location of the study area.

linear anomalies (up to 1000 nT) in the magnetic field. Terraces of the Hornsund Fault Zone are replaced by the flexure–fault belt of the continental slope, along which blocks of the pre-Tertiary substrate are subsided to maximal depths.

In the bottom topography, the Hornsund Fault corresponds to the eastern wall of the Atka Graben and is complicated by strike-slip faults. In the oceanic part of the Isfjord Plateau, the fault zone forms a system of terraces inclined toward the Atka Graben. Normal faults reflecting extension settings are reflected in the relief by orographic steps and asymmetrical river valleys, which are recorded in seismoacoustic profiles 20 020 and 20 022 across the Isfjord and Belsunfjord valleys.

The NW-trending faults are the oldest fractures that reactivated in recent time. The *NE-trending faults perpendicular to the shoreline* form, together with the fractures mentioned above, an orthogonal network characteristic of regions with active neotectonic movements.

These are fjords of the western Spitsbergen coast and their continuation at the continental shelf as wide valleys more than 200 m deep. The fjords of western Spitsbergen are developed after faults morphologically and structurally controlled by a system of listric faults along continental slopes of the Norway–Greenland and Eurasia oceanic subbasins.

A combination of transverse and longitudinal valleys makes up an intricate network of a structurally controlled hydrographic system, which is manifested well in the map of local morphostructures. Overlapping of the continuation of differently oriented valleys, their knee-shaped bends, and subordination of strike systems that are also typical of other morphological elements in this area—all these facts indicate significant control of the valley network by fault tectonics.

The neotectonic stage is marked by a sharp increase in the development of tectonic blocks and fractures due to intensification of the differentiation of tectonic stress fields.

The NE-trending fractures are represented by the oblique thrust type. The thrusts are usually undulating presumably due to different degrees of the competence of deformed rocks [3]. The strike-slip faults are commonly reflected in concordant horizontal displacements of morphostructures relative to each other. The normal faults, which indicate extension settings, are often reflected in the topography as orographic steps and walls of river valleys with asymmetrical transverse profiles [4]. The map of local topography demonstrates a distinct dextral strike-slip fault in the Belsund–Hornsund area (Fig. 2).

The *NNW-trending (oceanic) faults* are auxiliary ones relative to the axial Atka Trough or the continental slope edge. They acquire the near-meridional strike in the northern part of the study area.

Some of these faults probably crosscut the Knipovich Ridge and represent transform fractures.

The southwestern oceanic segment of the study area includes several faults located orthogonally to the above-mentioned fractures. One of them crosses a buried volcano, which is marked by a magnetic anomaly with an amplitude of 700 nT [2]. The seismic record demonstrates an apron composed most likely of volcanogenic sediments.

The Atka Graben. Similar to most of the passive continental margins, the Spitsbergen margin is accompanied by spacious sedimentary basins as troughs extended along the continental slope. The characteristic feature of such structures is the crust of different types: one wall of the basin is underlain by the continental crust, while another wall is underlain by the oceanic crust. This feature is observed in seismic records along geophysical profiles across the Atka and Pomorskii troughs. The latter trough extends along the West Barents margin.

The transverse profile of both these structures has a V-shaped form, and its oceanic part is always narrower. In the map of local morphology compiled by subtraction of the average relief from the general one, the Pomorskii Trough hosts a NW-trending narrow trench. Comparison with the CMP records reveals that the trench corresponds along its entire strike to the continent–ocean transition zone [2]. The Atka Trough represents a northern continuation of the previous structure. Its axis passes approximately below the shelf edge parallel to the shoreline. The maximal thickness of sediments in the axial part of the trough is 7–10 km. The Atka Trough is bordered by buried faults in the west and east. Its eastern wall is represented by terraces of the Spitsbergen zone, while the western wall is represented by the eastern slope of the Knipovich Ridge.

Figure 3 illustrates the combined CMP record and continuous seismoacoustic profile 22 017. The combined record makes it possible to estimate the role of exogenic and endogenic processes during the Neogene–Quaternary period of region development. From the west to east, the profile crosses the continental slope, its foot, and outer shelf to reach Prince Karl Land in the east.

The figure demonstrates extended systems of horst-shaped ridges and grabens formed during the Neogene. Processes of regional uplift during the terminal Neogene stimulated exogenic processes, denudation of ridges, accumulation of sediments in grabens, and formation of fans as swells on the continental slope and at its foot. These features indicate the development of intense and large-scale exogenic processes.

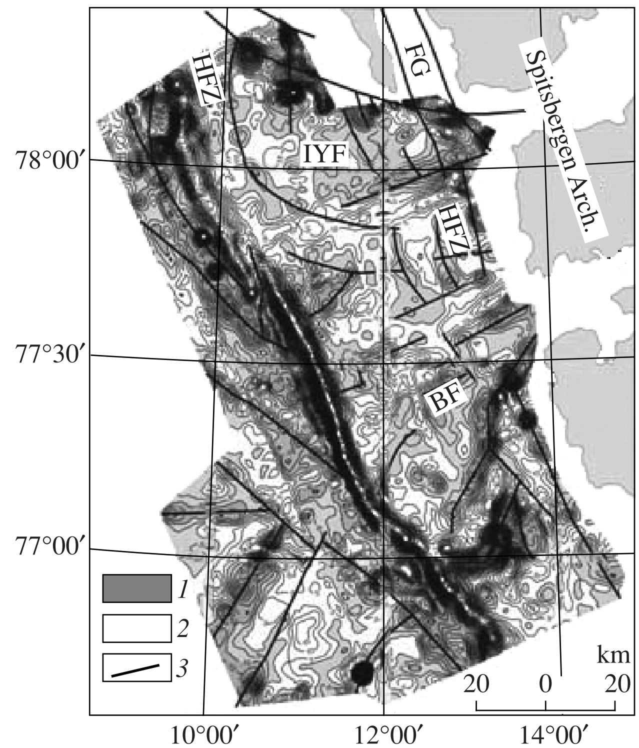

Fig. 2. Schematic neotectonic structure of the study region. (*1, 2*) local negative and positive morphostructures, respectively; (*3*) faults. (FG) Forlandsun Graben; (HFZ) Hornsund Fault Zone; (HPK) Prince Karl Horst; (IYF) Eastfjord Fault Zone; (BF) Belsunn Fault Zone.

According to [3], all Neogene sediments in the island segment of the West Spitsbergen Trough were eroded with the formation of the peneplain surface, which is located now well above the present-day sea level and crosses both the western dislocation zone and all the eastern structures in the northern part of the archipelago.

The activity of glaciers has intensified since the Eopleistocene. Therefore, fragments of the above-mentioned horst acquired the peculiar shape of sheep rock or whaleback with low-angle proximal and steep distal slopes.

The Pleistocene period was characterized by the transgressive–regressive cyclicity and growth of the continental slope. The main regressive cycles corresponding to glaciations are characteristic of the Middle (Riss, Saale) and Upper (Würm) Pleistocene. These cycles are marked by the erosion of sediments. Therefore, seismic complexes defined after [5] comprise undivided intervals: SSC A (Eopleistocene), SSC B (Middle Pleistocene), and SSC C (Middle–Upper Pleistocene).

The section demonstrates glacial topographies: terminal moraines of the Würm Glaciation and its phases, undulating topography left by a stationary glacier. Material was transported toward the ocean (regressive

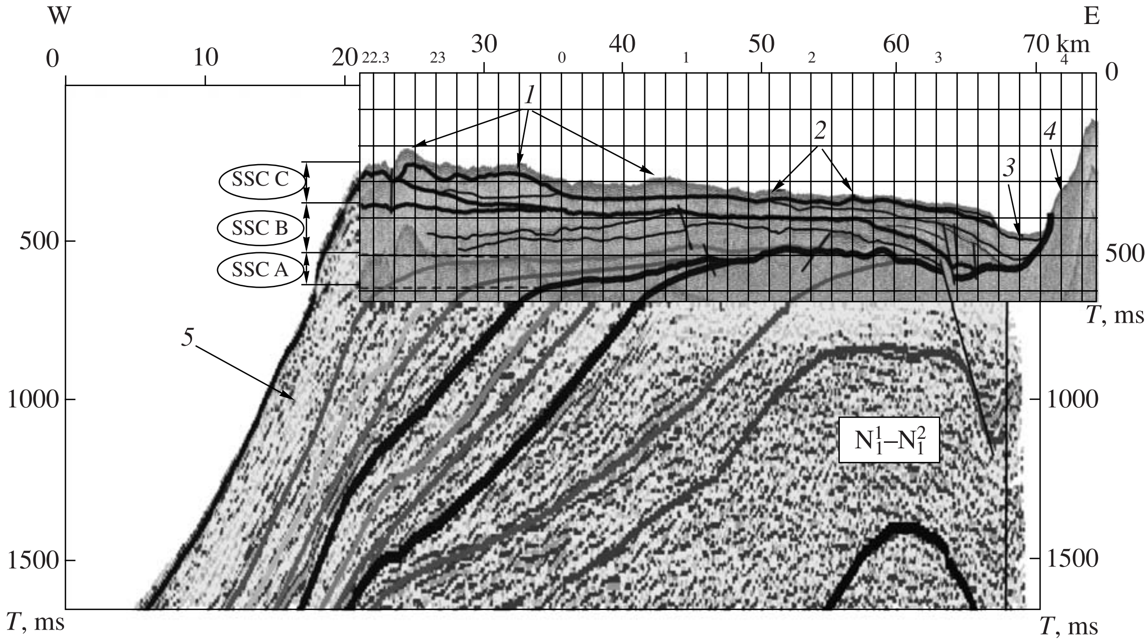

Fig. 3. Combined CMP and seismoacoustic NSP 22017 profiles. (N_1^1–N_1^2) Neogene complex; (SSC A) Eopleistocene complex; (SSC B) Lower–Middle Pleistocene complex; (SSC C) Middle–Upper Pleistocene complex; (*1*) moraine ridges; (*2*) undulating morphology; (*3*) thalweg of the Isdjupet Trench; (*4*) quest–ridge morphology; (*5*) continental slope.

periods) and trench (transgressive periods) to form the Isdjupet Valley [6]. The thalweg of the Isdjupet Trench is confined to the tectonic graben with a sharply asymmetric profile: one wall is composed of the quest ridge (Proterozoic rocks), while another wall is flat and consists of Pleistocene rocks.

Although the present-day structure of Spitsbergen formed in the Pliocene, block movements also continued later. The Neogene was marked by the most intense tectonic movements in the whole platform history of Spitsbergen and the formation of its present-day structure. The general uplift of the region in the terminal Pliocene terminated the formation of its Early Cenozoic structural stage.

Transverse grabens bounded by fractures of a higher order were formed on the coasts at terminal stages. The successive destruction of the West Arctic continental margin probably corresponded to the initial stage of the taphrogenic development of the crust [7, 8]. Such a scenario is typical of the excited endogenic regime and is accompanied by the formation of deep starved depressions and eventual transformation of the continental crust into the “oceanic” one. The neotectonic schematic map shows that the present-day morphostructure of the continental crust is subdivided into separate microplates by a system of grabens.

Thus, classical fjord coasts are located in areas where the younger taphrogenic regime is superimposed on the older continental (platform or orogenic) one [7]. Erosion of a part of incoherent sediments by Quaternary glaciations only emphasized their morphostructure. The Isdjupet and Belsundjupet valleys located in the study area are anomalously wide relative to their length.

Judging from the present-day configuration of the shores and fjords, they were formed by dominant near-meridional and near-latitudinal movements. Taking into consideration the fact that manifestations of the Holocene basic volcanism (6.5–4.0 ka ago) are confined to near-meridional faults, these faults also dominate at the present-day stage, when formation of the Late Cenozoic structure was still in progress. According to [9], belts of elevated seismicity indicate the reactivation of abandoned faults.

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