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The Relationship between the Lineaments and Tectonics of the Kandalaksha Gulf in the White Sea

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Abstract—The regularities of the evolution of the lineaments and weakened zones within the water area and coasts of the Kandalaksha Gulf are considered. Morphostructural analysis of the territory is made and the radial diagrams of lineaments in different parts of the study area are compared. An attempt to connect the structure of the lineament system in the study area with the tectonic evolution of the major regional structure, viz., the Kandalaksha Gulf, is made.

Keywords: lineaments, tectonics, faults, rift, morphostructure analysis, Kandalaksha Gulf
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INTRODUCTION

The White Sea is characterized by various types of coasts, which substantially differ in terms of geology and geomorphology (Fig. 1); this has long been of interest for geologists and geomorphologists. The major tectonic unit in the study area is the Onega–Kandalaksha (Baluev, Zhuravlev, and Przhiyaglovskii, 2009) or Kandalaksha (Avenarius, 2004) system of Riphean grabens, which determine the peculiarities of the regional tectonic evolution until the present. At the neotectonic stage, rifting inherited from the Middle–Late Riphean graben was activated (Baluev, Przhiyaglovskii, and Terekhov, 2009) (Fig. 2). A significant contribution to the modern relief formation is made by neotectonic rising of the territory due to glacioisostatic uplift of the entire Baltic Shield after removal of the ice sheet (Svendsen et al., 2004). It was shown in (Lavrov, 1960; Nikonov, 1967; Koshechkin, 1969) and in many other works that the region suffered a general uplift through the Holocene and that the uplift amplitude in the study area is more than 100 m.

The results of tectonic processes play a vital role in forming the tectonically caused relief of the Kandalaksha Gulf water area and coasts. Activation of tectonic motions within the limits of earlier-founded structures, as well as foundation of new structures, leads to a change of relief in the region as a whole (*Zemnaya kora*..., 1978; Baluev, Zhuravlev, and Przhiyaglovskii, 2009) (Fig. 2).

THE TECTONIC POSITION AND GEOLOGICAL STRUCTURE OF THE STUDY AREA

The White Sea is distinguished by a complex geological history and a large variety of natural processes. In the sense of tectonics, the White Sea Basin is located at the junction between the Fennoscandian Shield and East European Craton. The Kandalaksha Gulf, which is located in the western White Sea (Fig. 1), corresponds to the White Sea mobile belt of Mesoarchaean–Paleoproterozoic age. After the Karelian tectonomagmatic cycle, the entire region existed as a united platform structure. In the Oligocene, the neotectonic stage started for the White Sea region (Baluev, 2006; Slabunov, 2008). Isostatic uplift that involved the entire Scandinavian region mostly determines the present-day tectonic evolution of the study area.

In terms of geology, the Kandalaksha Gulf can be subdivided into two structural stages. The first one is represented by a crystalline basement composed of the rocks of the White Sea complex, which are Archaean in age. In the study area, this ancient complex is composed predominantly of biotite garnet–biotite, and amphibole–biotite gneisses; amphibolites, granitic gneisses, alumina shales, and quartzites; as well as by multiple intrusive bodies of different ages and compositions that pierce other rocks. The total thickness of these deposits is 8–10 km.

The second structural stage is cover. The most ancient rocks here are red Riphean sandstones that fill the aulacogenes in the crystalline basement. In the

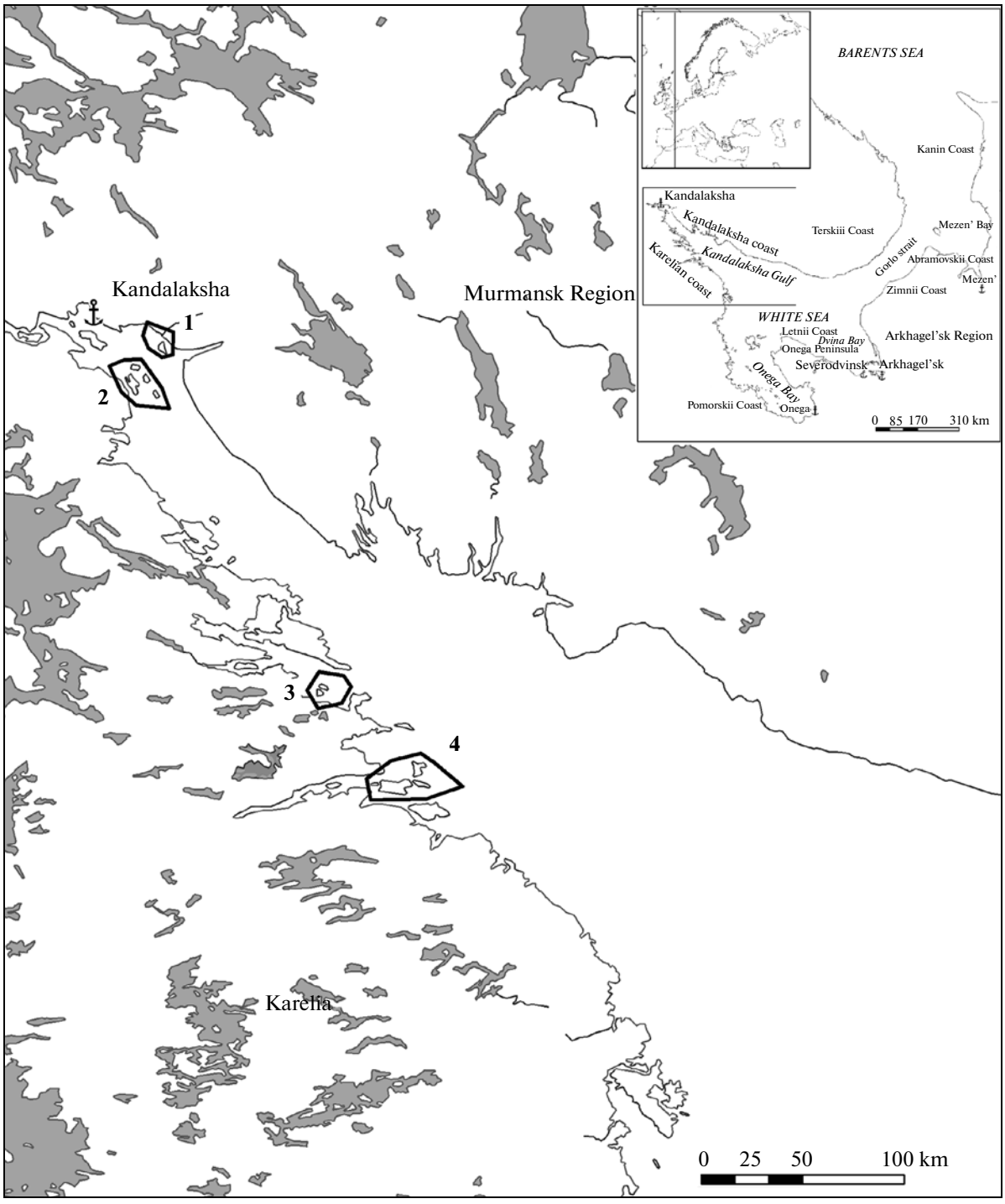

Fig. 1. The scheme of the study area location and sites (archipelagoes) of detailed study: (*1*) Luven'ga arch.; (*2*) Severnyi arch.; (*3*) Kuzakotskii arch.; (*4*) Keret arch.

southeast direction, the sandstones are covered with Vendian terrigenous deposits. All these ancient rocks on the bottom of the Kandalaksha Gulf are overlain by an almost continuous cover of young Pleistocene and Holocene deposits.

MATERIALS AND METHODS

The Kandalaksha Gulf was chosen as a key site for this study (Fig. 1). The term "lineament" was proposed for the first time in (Hobbs, 1904) to designate

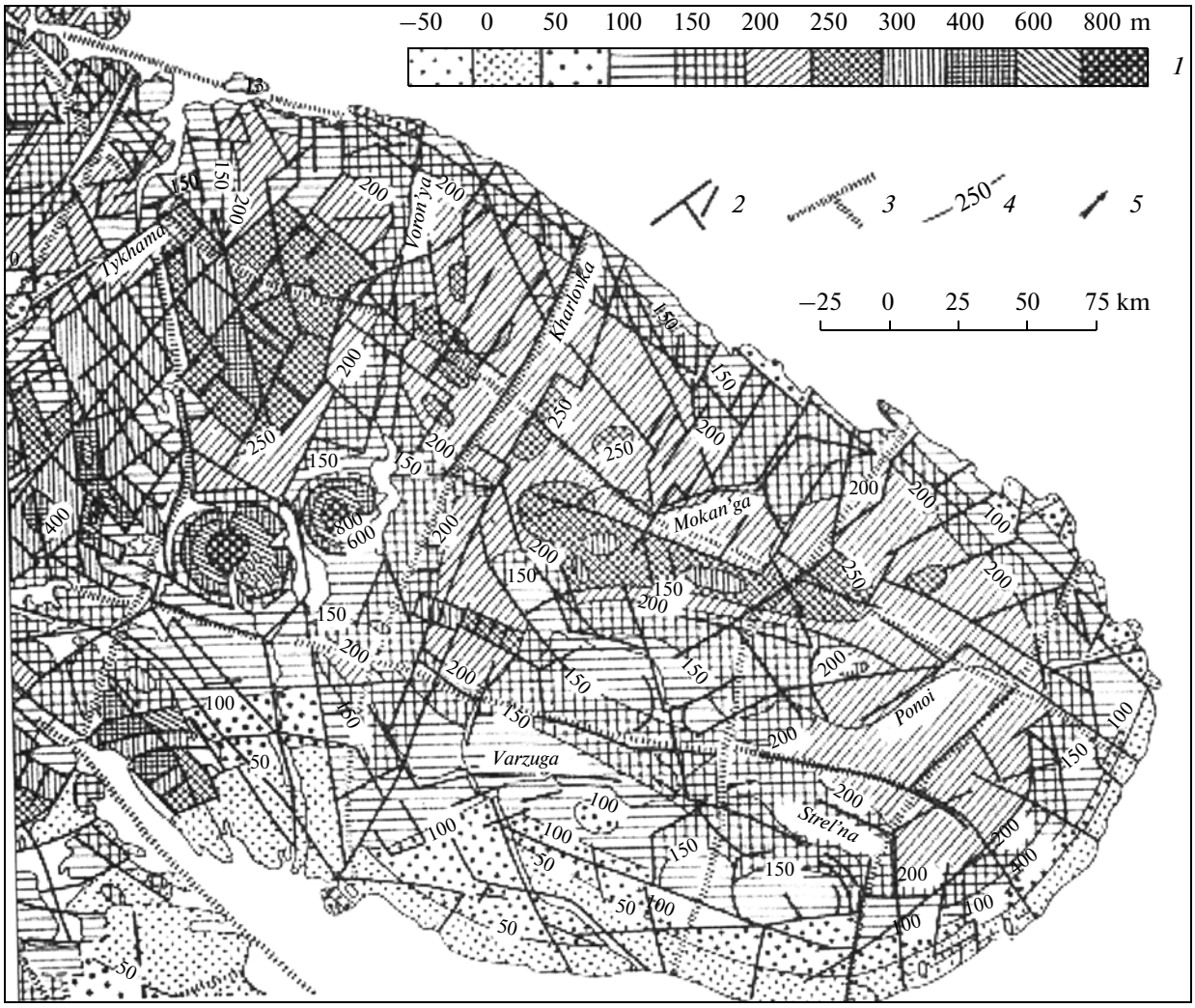

Fig. 2. Neotectonic motions in the eastern Baltic Shield, after (*Zemnaya kora*..., 1978): (*1*) scale of motion amplitudes; (*2*) faults renewed or founded at the neotectonic stage; (*3*) deep faults; (*4*) topographic curves of rising; (*5*) directions of block displacements.

linear landforms and geologic structures that are extended in one direction. Lineaments in the study area were distinguished and investigated by field and desk studies.

In the field studies, linear structural-relief features (elongated rocky scarps and massifs, linear portions of the coast, and linear elements of hydrological network) were distinguished. Linear zones of higher degrees of cracking, crack systems, and ruptures were identified and their strikes were measured.

The factual materials were then supplemented using the results of structural analysis of maps, as well as by the data from deciphering aerial and satellite images. The results of the lineament-system analysis were presented in the form of a GIS project involving topographic, bathymetric, geological, and tectonic maps, as well as satellite images of different scales. Based on deciphering the topographic and bathymetric maps, and remote sensing data, we distinguished the rectilinear elements of a hydrological network near the coast, rectilinear portions of the coastline, and rectilinear landforms on the Kandalaksha Gulf bottom. Special attention was paid to the lineaments that are located in the zones of large tectonic faults and weakened zones. As a result, a schematic map of the study area was constructed (Fig. 3). In addition, the distinguished lineaments were analyzed by the technique from (*Metodicheskoe*..., 1977) and presented in the form of radial diagrams that show the lengths and directions of the lineaments (Figs. 4 and 5).

RESULTS AND DISCUSSION

Analysis of the lineament network using the constructed map (Fig. 3) was made for each coast of the Kandalaksha Gulf, viz., the northwestern (Kandalaksha) and southwestern (Karelian), for the water area of the gulf, and in more detail for some sites that were

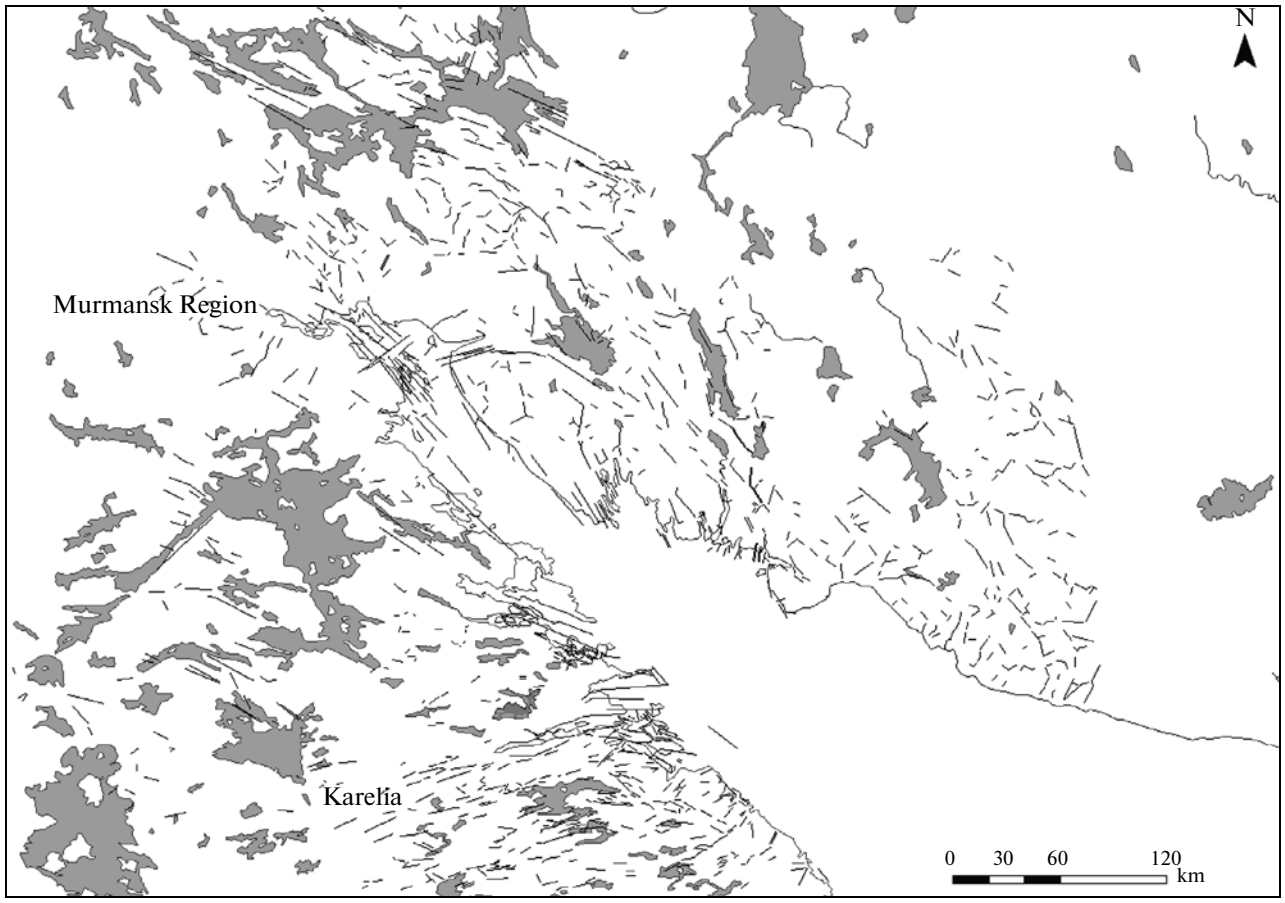

Fig. 3. A schematic map of the lineaments that were identified on the coast and in the water area of the Kandalaksha Bay based on the present study.

identified from navigation data (*Lotsiya*..., 2006): top of the gulf, Keret, Kuzakotskii, Luven'ga, and Severnyi archipelagoes (Fig. 1).

During analysis of the constructed circular diagrams of lineament strikes, it was revealed that the northwestern direction dominates within the limits of the water area and on the coasts of the Kandalaksha Gulf (Figs. 4a–4c). During the detailed consideration of the orientation of the lineaments on each coast of the gulf, the following regularity was found: a northwestern orientation of lineaments is characteristic for the Kandalaksha coast (Fig. 4b). There is a small peak of sublatitudinal lineaments in this circular diagram, because they often can be found in the southern part of the southwestern coast of the Kandalaksha Gulf (Fig. 2). A small number of sublatitudinally striking lineaments in the Kandalaksha coast are related to the pattern of structural tectonic relief. Within the Karelian coast (Fig. 4c), lineaments of northern, north–northwestern, and north–northeastern strikes dominate.

Analysis of lineament distribution and orientation at the top of the Kandalaksha Gulf revealed the predominance of north–northwestern and northwestern lineaments (Fig. 4d). On the coasts in the middle part of the Kandalaksha Gulf, the northwestern orientation of lineaments is characteristic (Fig. 4e), while northern and northwestern direction occur in the area that is adjacent to the mouth of the Kandalaksha Gulf (Fig. 4f).

Thus, it was verified that the distinguished lineaments are inherited after the directions of the major regional tectonic structures and feathering faults (Figs. 2, 4, and 5). The differences between the strikes of the lineaments for different coasts of the Kandalaksha Gulf show that the coasts inherited the Kandalaksha rift structures of a generally northwestern–southeastern orientation, with a large number of secondary faults connected with the rift.

As well, the lineament network within some archipelagoes was analyzed (Fig. 5). The formation of these islands was affected by the evolution of ancient tectonic structures and neotectonic motions.

For the Keret archipelago, the linear structures of a northern (submeridional) orientation dominate (Fig. 5a). The circle diagrams for the Karelian coast and the zone of Kandalaksha Gulf mouth demonstrate similar characteristics.

Among the linear structures in the Kuzakotskii archipelago, those of a north–northwestern orienta-

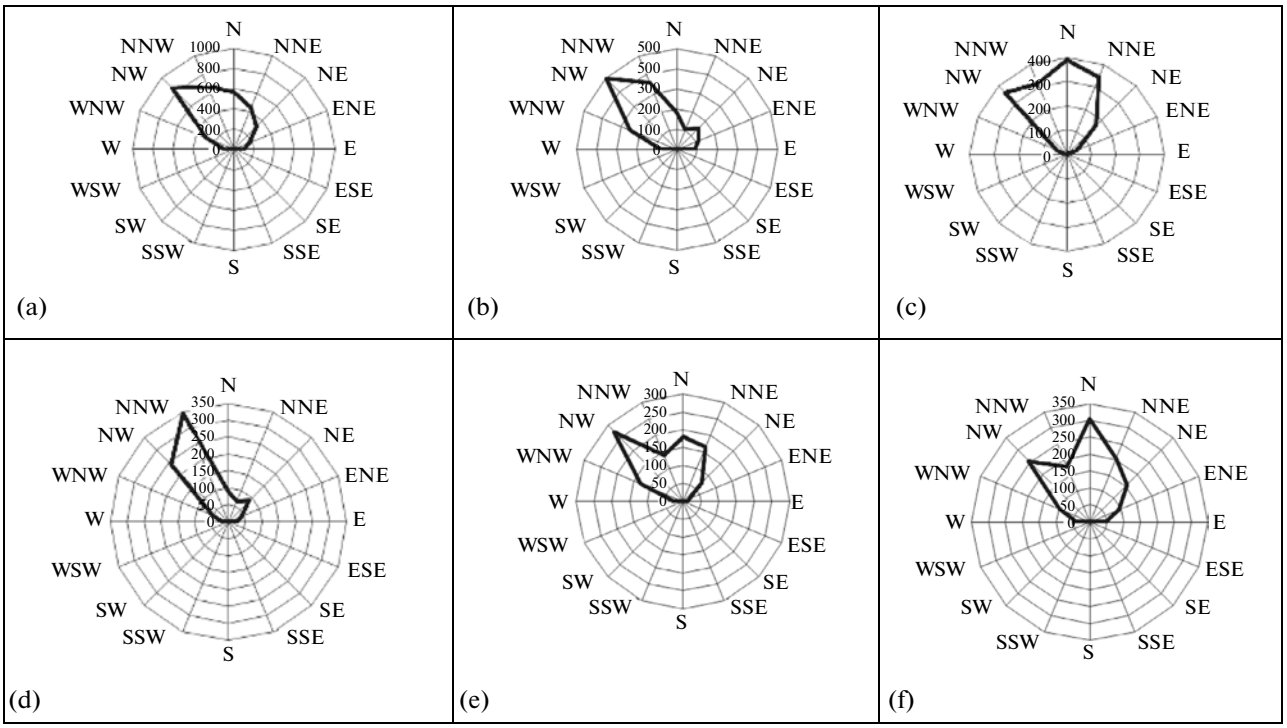

Fig. 4. Circle diagrams showing the strikes of linear structures for the Kandalaksha Bay and adjacent areas (a), for the Kandalaksha coast (b), for the Karelian coast (c), for the top of Kandalaksha Bay (d), for the central part of the bay (e), and for the mouth part of the bay (f).

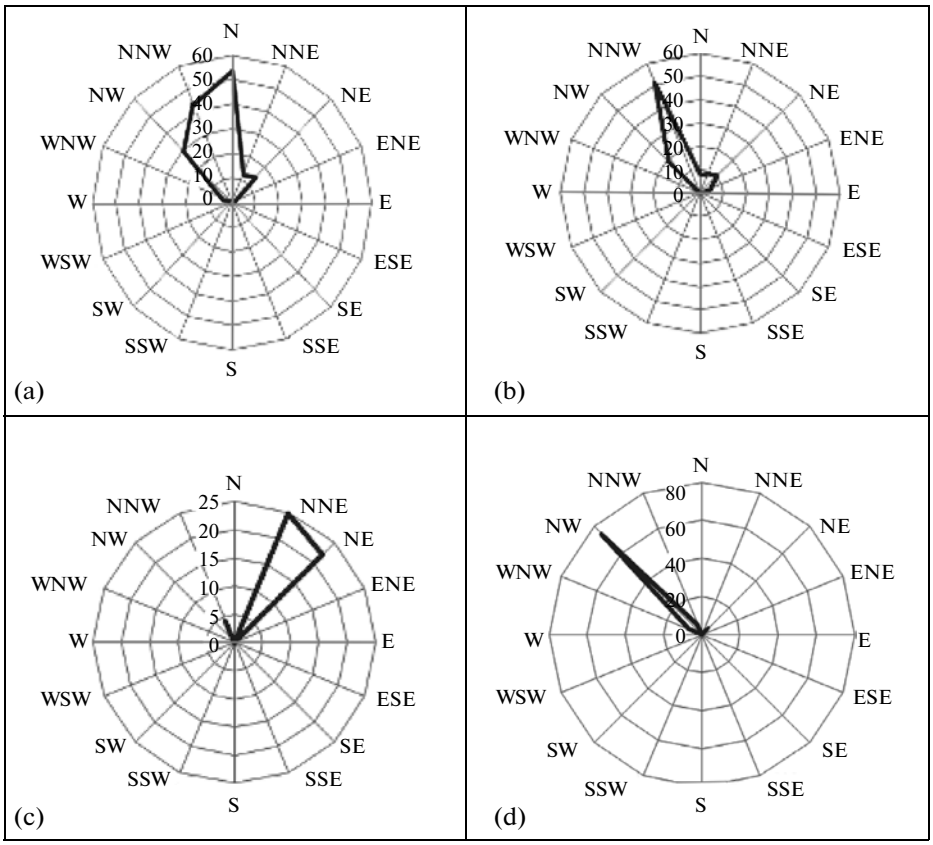

Fig. 5. Circle diagrams that show the strikes of linear structures in the areas of archipelagoes: (a) Keret, (b) Kuzakotskii, (c) Luven'ga, and (d) Severnyi.

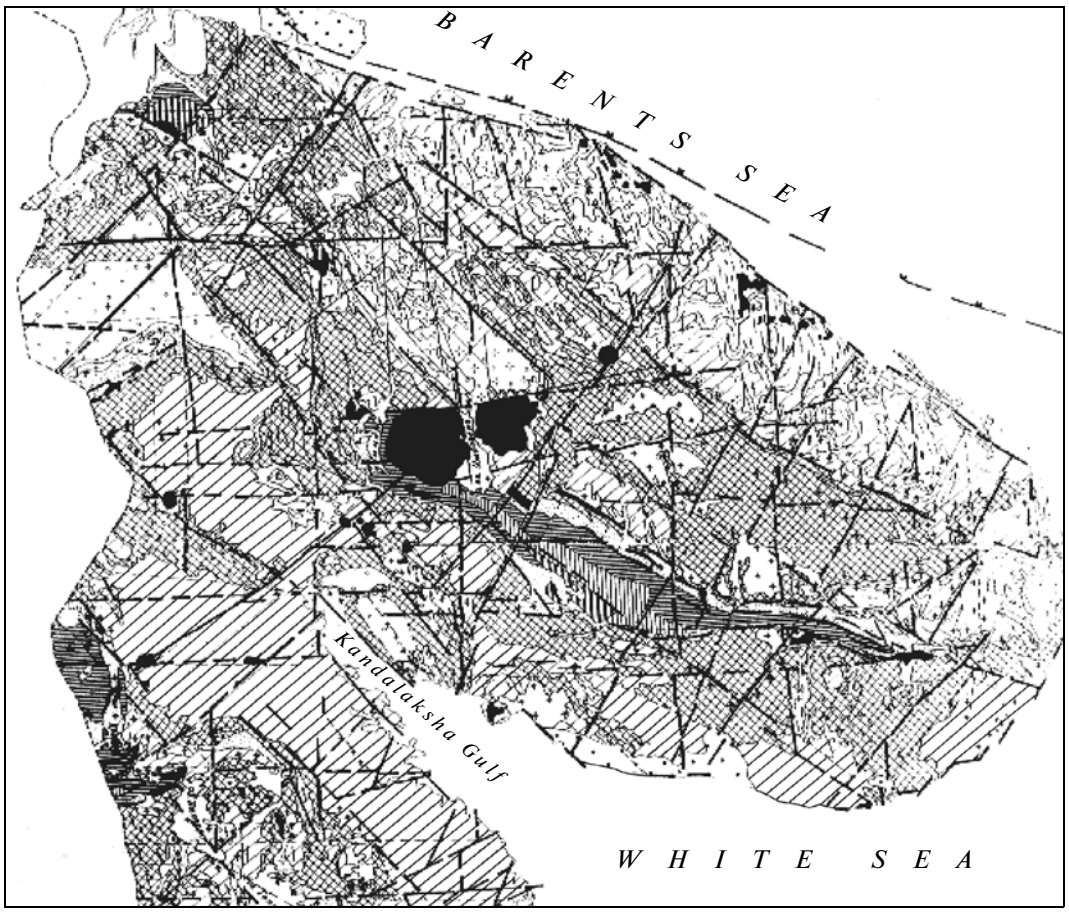

Fig. 6. The zones of major deep ("transparent") faults, after (*Tektonika*..., 1974).

tion are predominant (Fig. 5b), which are analogous to the entire Karelian coast and central part of the Kandalaksha Gulf.

The Luven'ga archipelago is confined by six lineaments that structurally make the archipelago a single block. The circle diagram for this archipelago (Fig. 5c) indicates that linear structures of north–northeastern and northeastern directions dominate here. The Luven'ga archipelago is oriented roughly in parallel to the Kandalaksha coast and lineaments are oriented across the strikes of the Kandalaksha coast lineaments.

For the Severnyi archipelago (Fig. 5d), northwest-oriented linear structures dominate. Such an orientation was also reported for the Karelian and Kandalaksha coasts and for the Kandalaksha Gulf top. These results suggest that linear structures of lower orders inherited the orientation of the larger linear structures.

When comparing these results with those of previous studies (Fig. 6), a clear clockwise rotation of lineament orientation from sublatitudinal to submeridional was found.

CONCLUSIONS

Most of the distinguished lineaments are characterized by northwest-to-southeast strikes, corresponding to the present-day active faults in the sides of the Kandalaksha rift. Archipelagoes that are oriented along the Karelian coast are confined by the northwest- and north–northwest-oriented lineaments. This is evidence of the submarine continuation of lineaments identified on land. The linear structures that confine the Luven'ga archipelago are oriented across the strike of lineaments that were identified in the zone of the Kandalaksha coast, suggesting site location at the crossing between lineament systems (the so-called node structure).

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