ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 417A, No. 9, pp. 1337–1341. © Pleiades Publishing, Ltd., 2007.
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GEOLOGY

# New Data on the Tectonics and Structure of the Sedimentary Cover of the White Sea Rift System

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Presented by Academician Yu.M. Pushcharovsky December 12, 2006

Received January 23, 2007

**DOI:** 10.1134/S1028334X07090103

The White Sea is an inner sea of Russia, and its geology and geophysics are poorly studied. According to current ideas, rift structures of the Mezen syneclise extend to the White and Barents seas and bend round the Kola Peninsula in the southwest and northeast [1, 2, 4, 7, 8, 13]. Until the present time, these ideas were based only on fragmentary data of the analysis of potential geophysical fields and mainly on materials of the geology of land framing.

The analysis of new marine CMP SR, gravity and magnetic survey, and continuous seismic profiling data obtained in 2003 and 2004 (MAGE) in combination with the results of geological and geophysical works on land allowed us to characterize for the first time the inner structure of the White Sea rift system (Fig. 1).

From the tectonic point of view, the White Sea region is located in the northeastern framing of the Baltic Shield overlain by the sedimentary cover of the Russian Plate. The region is composed of Riphean, Upper Vendian, and Upper Paleozoic rock complexes and Quaternary sediments.

The Mezen rift system comprises the Mezen Graben and the Ponoi Trough distinguished in Mezen Bay and the White Sea Funnel. The White Sea rift system includes the Kandalaksha, Kerets, and Onega grabens spatially related to the White Sea basin (Fig. 1).

The two graben systems are separated by the Terskii terrace mainly composed of Lower Archean gneiss–granites and granodiorites. The Terskii terrace has clear boundaries. The southwestern boundary with the Kerets graben extends over a large fault with a total amplitude of ~1 km, which is traced in the southeastern direction from the Terskii shore to the Zimnii shore. The northeastern boundary with the Ponoi Trough is represented by the Zolotitsa tectonic zone, which extends from the Zimnii shore via the White Sea Neck to the eponymous Funnel, and the system of the NW-trending stepwise faults that probably make up the southwestern slope of the Mezen graben as well. The amplitude of faults along the Zolotitsa zone reaches 2 km. The Terskii terrace plunges in the southeast direction along the fault system below the sedimentary cover of the Russian Plate. The terrace on the Zimnii shore is complicated by the Zolotitsa and Ruchei salients and troughs of the Leshukon rift system. The thickness of the sedimentary cover in the offshore area of the Terskii terrace does not exceed 1 km. The sequence is composed of Riphean, Vendian, and Quaternary sediments. Riphean rocks fill up pockets in the crystalline basement, whereas Vendian and Quaternary sediments overlap the deeply eroded surface of underlying rocks.

The asymmetrical Kandalaksha graben, 220 km long and 60 km wide, consists of two troughs 7 and 8 km deep. Its southwestern steep slope is in tectonic contact with the crystalline basement of the Karelian salient (Fig. 1, section A–B). The contact represents a fault (amplitude 8 km), which flattens out with depth. Structures of the southwestern slope of the trough, which are pressed to the Karelian salient, are likely composed of detached and crushed rocks of the basement and foothill sediments of horsts. The fault boundary clearly outlined in the bottom topography, as well as wave and potential fields, is traced as an arc from the Karelian shore to the Onega Peninsula (Fig. 1). Dextral displacements of the fault boundary along the NE-trending faults are noted. The northeastern gentle slope of the trough is complicated by normal faults and reverse thrusts. The main fault is observed on the Olenitsa swell, which is an elevated block of the crystalline basement traced in the offshore area as a narrow band of positive gravity and negative magnetic anomalies. The swell flattens out upward the Riphean sedimentary sequence. The swell makes up a knee-shaped bend on the White Sea Neck traverse and gradually disappears

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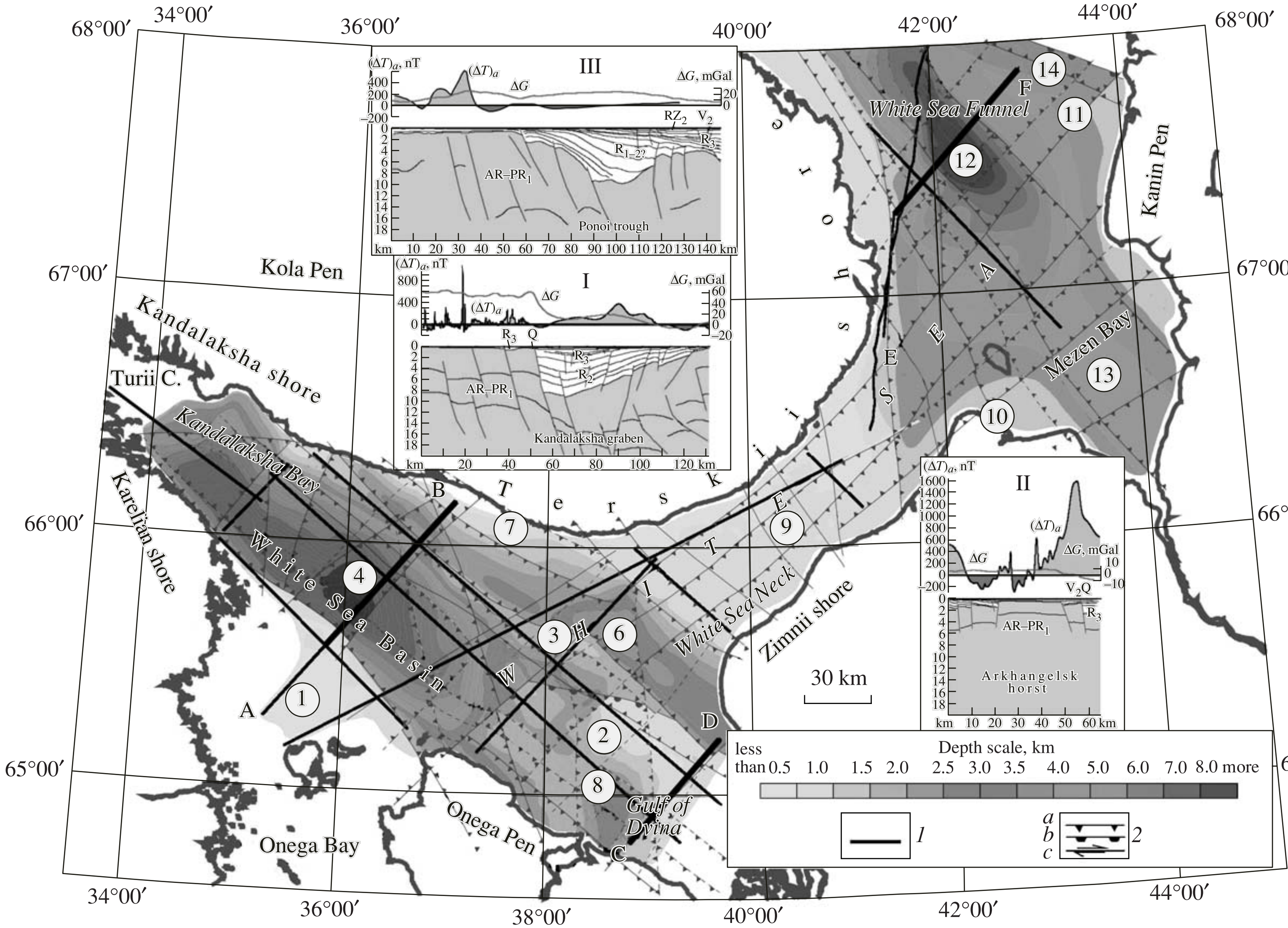


**Fig. 1.** Structural scheme of the heterogeneous basement surface. (I, II, III) Geological–geophysical sections along lines A–B, C–D, and E–F. (*1*) CMP seismic reflection profiles; (*2*) tectonic dislocations: (*a*) normal faults; (*b*) overthrusts; (*c*) strike-slip faults. Numbers in circles denote principal structural elements of the basement: (1) Karelian salient, (2) Arkhangelsk horst, (3) Olenitsa swell, (4) Kandalaksha graben, (5) Onega graben, (6) Kerets graben, (7) Varzuga monocline, (8) Maloshuika–Una trough, (9) Terskii terrace, (10) Kuloi salient, (11) Chizha salient, (12) Ponoi trough, (13) Mezen graben; (14) Shoina trough.

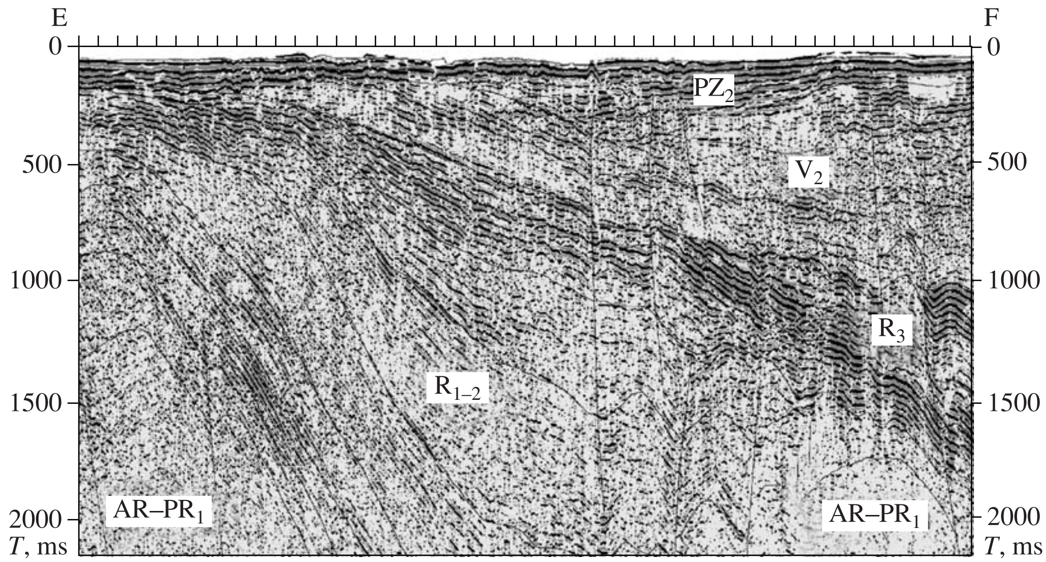


**Fig. 2.** A fragment of the seismic section along line E–F.

in the NE-striking tectonic dislocation zone. However, the swell can continue in the southeast as a terrace on the Arkhangelsk horst. The Kandalaksha graben is conjugated with the Arkhangelsk horst in the southeast.

In the south, the Kandalaksha graben crosses the basement salient and adjoins the Onega graben, which is represented in the offshore area by a part of the Solozero terrace.

The Kerets graben is about 40 km wide, and its basement subsides to a depth of 3 km. It borders the Kandalaksha graben and Arkhangelsk horst on the southwest. The boundary between the grabens passes along the White Sea suture zone located between the Kola and Karelian blocks of the White Sea region. The suture is expressed by an intense positive magnetic anomaly extending in the offshore area from the Turii Peninsula to the southeastern Zimnii shore and further to the Timan trough. This boundary represents an overthrust along the Olenitsa swell. The southwestern steep slope of the Kerets graben is pressed to the Olenitsa swell, while the northern gentle slope is represented by the Varzuga monocline. The northeastern slope is expressed by a steep bench of the Terskii terrace.

The Varzuga monocline occupies a part of the Terskii shore of the Kola Peninsula. Structures of the monocline plunge to the southwest along steep faults. A sinistral displacement of the Kerets trough axis along the tectonic zone is observed near the White Sea Neck. This zone of subparallel NE-trending faults is traced in the White Sea offshore zone from the Onega Peninsula along the Neck to the Kanin Peninsula. It is known as the Arkhangelsk tectonic zone on the Zimnii shore.

The Arkhangelsk horst has distinct tectonic boundaries. In the northeast and southwest, structures of the horst plunge as terraces into the Onega and Kerets grabens (Fig. 1, section C–D). Judging from seismic data and anomalies of potential fields, the horst represents a system of NW-striking linear blocks of different levels, which are crosscut by NE- and NS-striking transverse faults. The faults determine the structural pattern of the Maloshuika–Una trough, which is superposed on the Arkhangelsk horst and Onega graben.

The Maloshuika–Una trough is located on the crushed basement of the Arkhangelsk horst and represents a branch of the Onega graben. The depth of the graben does not exceed 2.5 km.

The Ponoi trough formed on the northwestern extension of the Mezen graben. The observed displacement of the Ponoi trough axis relative to the Mezen graben axis is determined by dextral strike-slip faults of blocks along the Arkhangelsk tectonic zone or by a bending of the rigid core in the basement by the Mezen rift system. In the south, the trough is bounded by the Kuloi salient. In the southeast, the trough adjoins the Mezen graben via a system of transverse horsts and grabens controlled by the Arkhangelsk tectonic zone.

In the east, the Ponoi trough is bounded by the Chizha (Nes [6]) salient. The salient was formed probably at the boundary between the Middle and Upper Riphean. It was incorporated later into the foreland zone during the formation of the Kanin–Timan fold–thrust belt (Fig. 1, section E–F). The salient extends from the Kanin Peninsula to the offshore area of the White Sea Funnel. Its structures pinch out near 42° E, and the Ponoi trough adjoins the narrow Shoina trough, which is sandwiched between the Chizha salient and the Cape Ludovatykh swell. The boundary between the Russian Plate and the Kanin–Timan megaswell is drawn here along a major thrust zone [8, 9].

The Ponoi trough is closed along a NE-trending fault zone near Cape Svyatoi Nos. Offshore extensions

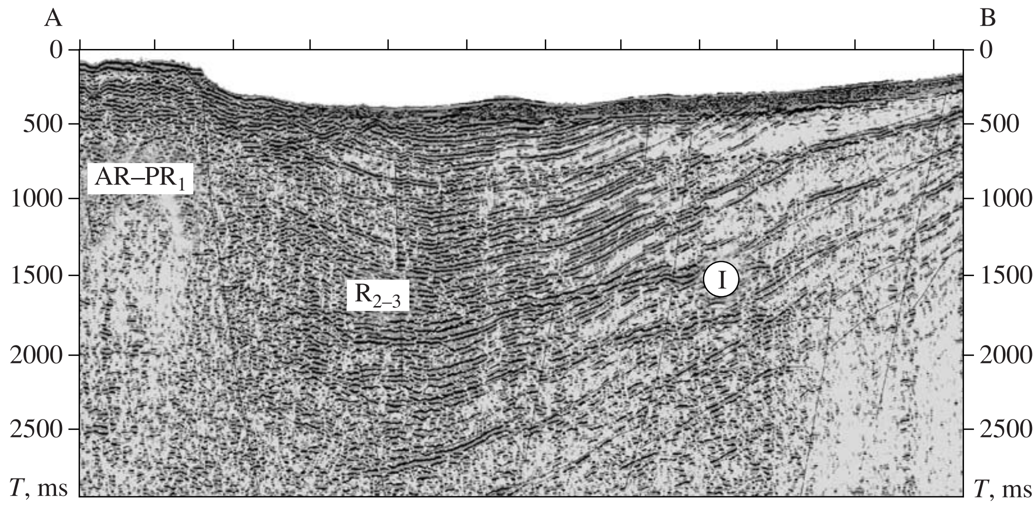


**Fig. 3.** A fragment of the seismic section along line A–B. (I) Intrusion-type wave field anomalies.

of structures of the Kanin–Timan belt located parallel to the trough axis also terminate in this area [7].

Two structural–tectonic stages are distinguished in the sedimentary sequence of the White Sea region. The lower stage is represented by Riphean synriftogenic deposits, the maximal thickness of which makes up 8 km in the Kandalaksha graben and 9 km in the Ponoi trough.

Based on the mode of occurrence and the seismic record, the Riphean sequence is subdivided into two complexes. The lower complex fills up grabens. The upper complex smoothes away the basement relief and is marked by a more regular and prominent wavy pattern. Change in the seismic record is likely to reflect variations in sedimentation conditions and the lithological composition of rocks. A distinct bedding characteristic of both complexes indicates weak metamorphism of the Riphean sequence.

The Riphean sedimentary sequence is represented more completely in the Ponoi trough (Fig. 2). In general, the seismic characteristic of its section corresponds to Riphean sequences in grabens of the White Sea–Leshukon–Mezen rift system, which are distinguished on land along the CMP profile I [1, 3]. Stratification of Riphean deposits was carried out based on sections of the Ust-Nyafta and Sredne-Nyafta parametric boreholes. Based on the analogy with land, we can suppose that the lower sedimentary complex of the Ponoi trough corresponds to Lower–Middle Riphean rocks, whereas the upper complex corresponds to Upper Riphean rocks. A hiatus approximately 150–300 Ma long is established between these complexes in grabens of the rift system. In contrast, such a hiatus is absent in the Ponoi trough.

With respect to the seismic record, Riphean complexes of the Kandalaksha graben resemble the lower sedimentary complex of the Ponoi trough (Fig. 3). Characteristic anomalies of the wave and potential fields suggest the presence of effusive rocks within the Riphean sequence of the graben. It should be noted that rocks of the tholeiite–basalt formation (dolerites, basalts, and their tuffs) were penetrated by boreholes in the upper part of the Middle Riphean (Solozero Formation) on the Onega Peninsula [10]. The reference horizon of effusive rocks may serve as a reason for distinguishing Upper Riphean (Verkhnetersk Formation) and Middle Riphean (Turii Formation) complexes that are comparable with the Nenok and Solozero formations, respectively, of the Onega graben. However, no clear indication of stratigraphic or structural unconformity between these formations has been revealed in the Riphean sequence of the Kandalaksha graben.

It is likely that trap rocks are widespread in the northwestern and central parts of the Kandalaksha graben and the southeastern part of the Kerets graben. The major fault zone of the White Sea suture could serve as a conduit. The fault zone extends from Cape Turii to the offshore zone along the Olenitsa swell and the southwestern slope of the Kerets graben.

Riphean sediments in the central part of the Kandalaksha graben are deformed into gentle folds. The axes of the folds are parallel to the longitudinal axis of the graben. Deformation of beds increases toward the Kandalaksha shore and the White Sea Neck.

Postsedimentary folding and faulting of Riphean rocks are characteristic of the eastern White Sea basin and especially the Arkhangelsk tectonic zone. CMP profiles intersect the Kerets graben in the overthrust zone. Two seismic complexes are distinguished in the Riphean section. The upper (probably Late Riphean) complex characterized by prominent reflections overlies the gentle eroded surface of the lower seismic complex. The more dislocated and metamorphosed lower complex is represented by volcanosedimentary rocks probably of Early–Middle Riphean age.

The sedimentary section of the Maloshuika–Una trough represents a corrugated sequence presumably of Late Riphean age. Late Riphean sediments also overlie benches of the Arkhangelsk horst.

The upper structural–tectonic stage overlaps with a sharp angular unconformity the eroded surface of the lower stage and the basement. It is subdivided into three structural complexes represented by Vendian, Upper Paleozoic, and Quaternary sediments. In general, the thickness of the stage increases eastward and makes up 2500 m in the Shoina trough.

The Vendian complex is developed in the eastern part of the White Sea. Its thickness varies from 0 m near the coast of the Kola Peninsula and in the Kandalaksha graben to 1500 m in the northeastern part of the Ponoi trough. Upper Paleozoic rocks are established only in the White Sea Funnel, where their thickness does not exceed 300 m. Quaternary sediments overlie the eroded surface of the sedimentary cover and basement rocks of different ages. The thickness of Quaternary sediments is as much as 150 m in some places (average ~30 m). They are likely dominated by moraine sediments.

The analysis of the materials presented above suggests the following conclusions. The base of basins in the White Sea region incorporates an Early–Middle Riphean paleorift system, which is differentiated into two branches bounding rock blocks of the Kola Peninsula in the north and south. Grabens and horsts of the White Sea system are deformed by numerous transverse faults, often with a strike-slip component. The White Sea intracraton branch (Kandalaksha and Kerets grabens) has a more complicated structure. The branch located in the White Sea Funnel (grabens of the Mezen Bay and the Ponoi graben) evolved under pericraton conditions and exhibits a thicker sedimentary cover that includes the Riphean–Paleozoic complexes in addition to the Riphean synriftogenic deposits. In the course of evolution, the paleorift structures underwent multiple activation, particularly at the beginning of the Late Vendian and in the Late Devonian, as demonstrated by the corresponding age of basaltoid magmatism [2, 5, 14]. At the same time, deformations of the sedimentary cover mentioned above suggest the influence of collision processes on this part of the East European Craton in the Late Riphean–Early Vendian and Cadomian [8, 9, 11, 13]. According to our estimates, the value of erosion of rocks in the northeastern Kandalaksha graben related to these processes may reach nearly 5 km.

Like many elements of the Barents Sea shelf, despite a sufficiently old age, basins of the White Sea rift system exhibit an inherited morphostructural pattern in the bottom relief.

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