RUSSIAN JOURNAL OF EARTH SCIENCES, VOL. 7, ES5001, doi:10.2205/2005ES000171, 2005

The quasiplatform sediments of the East European Platform

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Received 5 May 2005; revised 5 June 2005; accepted 5 July 2005; published 5 August 2005.

[1] The subject of this paper is the structure of the peculiar rock complex of the East European Platform, composed of the rocks dated 1750 Ma to 1300 Ma and known as a quasiplatform rock cover. The western and eastern segments of the platform differ greatly in terms of the lithology and thickness of their rocks. The quasiplatform sediments have been subdivided into the lower and upper subtypes. The lower subtype is developed mainly in the west, and the formation of the structural features composed of these rocks is supposed to have been associated with the process that operated in the Ural Mountains. *INDEX TERMS:* 0905 Exploration Geophysics: Continental structures; 8015 Structural Geology: Local crustal structure; 8038 Structural Geology: Regional crustal structure; *KEYWORDS:* sedimentary cover, basement, magmatism, tectonics, structural feature.

Citation: Nagornyi, M. A., and V. G. Nikolaev (2005), The quasiplatform sediments of the East European Platform, *Russ. J. Earth. Sci., 7,* ES5001, doi:10.2205/2005ES000171.

1. Introduction

[2] The authors of the numerous papers published for the East European Platform subdivide its rocks into the crystalline basement and the sedimentary cover. The sediments are usually classified into four types [*Garetskii,* 1983; *Yanshin et al.,* 1974]: the protoplatform, quasiplatform, cataplatform, and orthoplatform types. The protoplatform sediments are of limited extent, being most widely developed on the Baltic Shield [*Leonovet al.,* 1995], where they accumulated simultaneously with the early cratonization of the basement.

[3] The quasiplatform sediments began to accumulate during the late cratonization stages, which were accompanied by igneous activity, both in the form of granitization and volcanic activity. The rocks of this complex are almost horizontal being widespread throughout the East European Platform in small troughs and grabens, or as fairly broad fields.

[4] *Yanshin et al.* [1974] believe that the quasiplatform sedimentary rocks, filling the earliest structural features of the platform type, accumulated in the zones of the post-Karelian folding, most of them being platform-type sediments, the rocks of the orogenic type (molassic types) being subordinate. The quasiplatform sediments differ from the platform-type rocks by their higher deformation and poor metamorphism. Laterally, the structural features filled with quasiplatform sediments are conjugated with orogenic belts and geosynclines. In terms of their geophysical parameters (velocities and densities), the rocks of the quasiplatform cover differ greatly from the underlying rocks (basement and protoplatform sedimentary rocks) and also from the overlying rocks (cata- and orthoplatform sediments). The quasiplatform sediments accumulated during a long-time period ranging from 1750 Ma to 1300 Ma, this proving the substantial role of this time period for the further evolution of the East European Platform (EEP).

[5] The quasiplatform rocks are overlain by the cataplatform sedimentary rocks, ranging in age from the Upper Riphean to the Middle Vendian, which fill the large aulacogens of the platform. They are represented by sedimentary rocks and were almost nowhere found to have been deformed. Finally, the uppermost part of this rock sequence is represented by an orthoplatform sedimentary cover forming the Russian platform, where it overlies, with a structural unconformity, as a continuous cover, all of the underlying rocks, the rocks of the orthoplatform cover being exclusively sedimentary ones.

[6] The proto-, cata-, and orthoplatform sediments have been studied fairly well [*Makhnach et al.,* 2001; *Kazantsev*

ISSN: 1681–1208 (online)

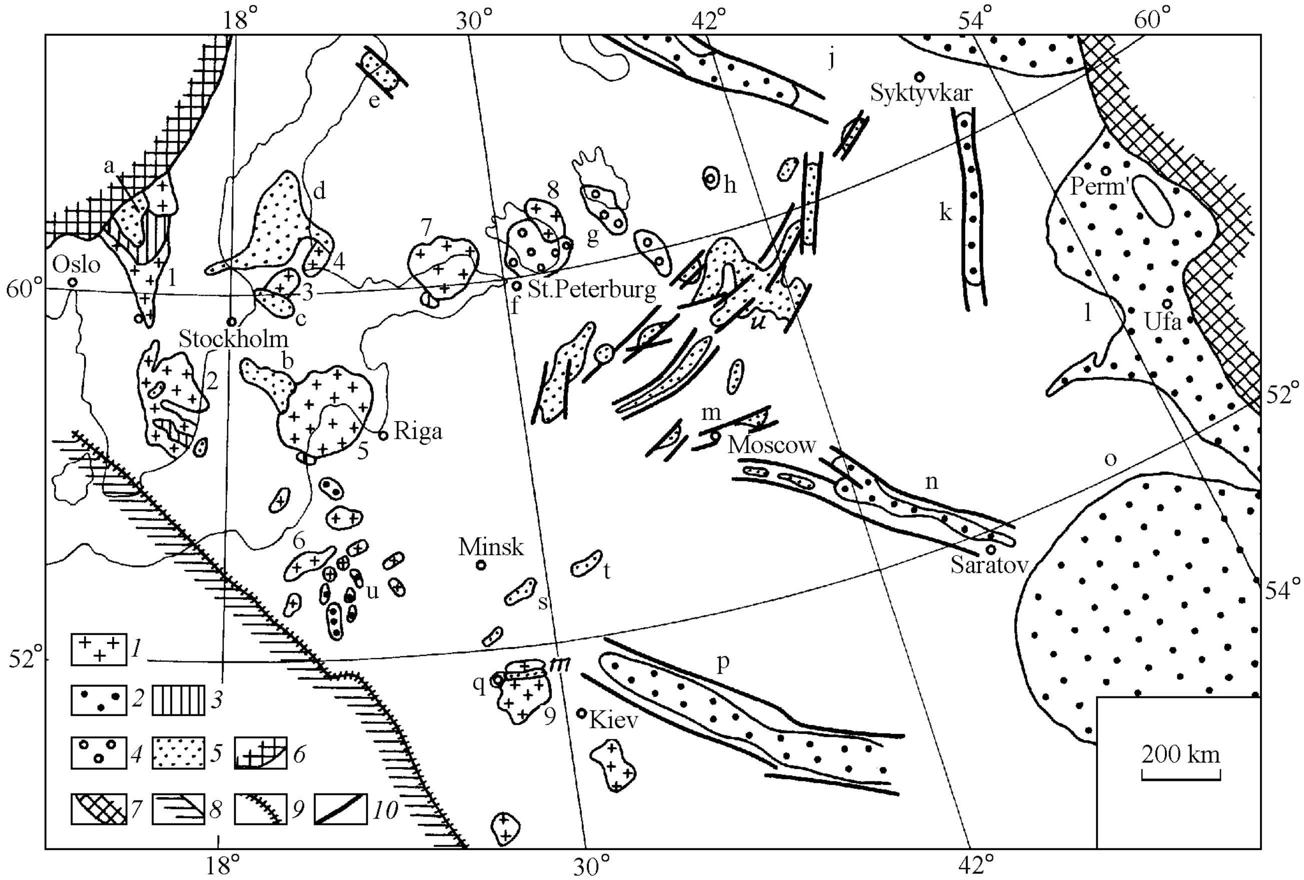

Figure 1. Schematic map of the quasiplatform sediments in the central part of the East European Platform.
(1) plutonic rapakivi granite, anorthosite, and gabbro anorthosite complexes ranging from 1700 Ma to 1500 Ma in age. Indicated by figures are the largest plutons: (1) Vermland, (2) Smoland, (3) Aland, (4) Laitila, (5) Riga, (6) Suvalakskii, (7) Vyborg, (8) Salma, (9) Korosten; (2) undifferentiated quasiplatform rock cover; (3–4) lower quasiplatform sediments: (3) mostly volcanic rocks, (4) mostly terrigenous rocks; (5) upper quasiplatform sediments; (6–8) the rocks surrounding the East European Platform: (6) the Caledonides of Norway, (7) the Ural fold area, (8) European Hercinides and Alpine folded area; (9) SW marginal suture; (10) faults confining the quasiplatform grabens.
The letters denote the largest basins and grabens filled with quasiplatform sediments: (a) Tryusil-Dala, (b) Gotska-Sanden, (c) Sedra-Quarken, (d) South Bothnian, (e) Mukhos, (f) Ladoga, (g) South Onega, (h) Onosh, (i) Middle-Russia aulacogen, (j) Mezen fold system, (k) Vyatka graben, (l) Volga-Ural region: Kama-Belsk, Sergiev Abdula and other aulacogens, (m) Gzhatsk and Moscow grabens, (n) Pachelma (Ryazan-Saratov) aulacogen, (o) Caspian depression, (p) Dnieper-Donetsk basin, (q) Belokorovichi basin, (r) Ovruch basin, (s) Bobruisk basin, (t) Krasnopolsk basin, and (u) Mazur basin. Some of the small structural features are shown out of scale.

et al., 2002; *Yanshin et al.,* 1974; to name but a few]. The protoplatform sediments are well known because of their location on the Baltic shield, where they are exposed. The cata- and orthoplatform sediments are known because of the numerous holes that were drilled there and a broad network of geophysical profiles (seismic CDP reflection and refraction and geoelectric surveys). The quasiplatform sedimentary rocks were penetrated by single holes and were surveyed along the relatively small number of regional CDP reflection profiles. For this reason its spatial extent and changes in lithology from one area to another, as well as the geodynamic conditions of sediment accumulation, are of great interest for reconstructing the platform evolution and deriving the theories of their future evolution. The aim of this study was to accumulate all geological and geophysical data available for the quasiplatform sedimentary rocks and to solve some of the problems mentioned above.

2. Review of the Data Available

[7] Our analysis of the geological and geophysical data available allowed us to compile a map for the propagation of the quasiplatform sedimentary cover for the whole territory of the East European Platform (Figure 1), using the criteria

of mapping the sediments, mentioned above. The examination of the resulting map showed that there were three large regions of the platform, where the quasiplatform sedimentary rocks differ markedly in their composition, thickness, and structure. These regions are the western, central, and eastern parts of the platform. The data available for these regions are reviewed below in this order.

2.1. The Western Part of the Platform, Including the Baltic Shield

[8] In the western part of the East European Platform, the previous researchers of this territory [*Aizberg et al.,* 2002; *Garetskii,* 1983; *Makhnach et al.,* 2001], to name but a few, used the term "quasiplatform sedimentary cover" to denote the fragments of the volcanogenic sedimentary rocks resting on the crystalline basement [*Garetskii,* 1976, 2001; to name but a few]. These rocks are usually poorly metamorphozed and rest almost horizontally on the crystalline basement, this distinguishing them from the typical basement rocks. They fill small grabens, graben-synclines, and basins in the areas of the Baltic and Ukrainian Shields, the Belorussian Anteclise, and the Baltic Syneclise.

[9] The radioisotope ages of these rocks vary widely from 1750 Ma to 1300 Ma, embracing the upper part of the Paleoproterozoic (Staterian) and the early half of the Mesoproterozoic (Early Riphean).

[10] As follows from the absolute age dating, the oldest poorly deslocated rocks in the West of the East European Platform are the Vepsian rocks of Karelia, the Subeotian rocks of Sweden, and the rocks of the Pugachev Series of the Ukrain [*Esipchuk et al.,* 1999].

[11] As follows from their absolute dating and positions in the rock sequence, the rocks of the Petrozavodsk and Shoksha formations, outcropping along the western coast of the Onega Lake, have been dated Vepsian. The Petrozavodsk Formation is composed of gray and greenish gray quartz sandstones, argillite, and phyllite-like shale. Thin basalt flows have been found locally. The thickness of the exposed rocks is about 350 m. They are overlain by the Shoksha Formation of red quartz sandstone beds interlayered by siliceous sericite shales and conglomerates. The thickness of this formation is as large as 400–500 m. The Vepsian rocks are intruded by dikes and sills of basic rocks. The results of the absolute dating of the igneous rocks (diabase) from the sedimentary cover range from 1710 Ma to 1755 Ma [*Bibikova et al.,*1990]. The Vepsian rocks are almost horizontal or inclined slightly to the east, producing a large synclinal fold, the axial line of which extends under the southern area of the Onega Lake. As follows from the geophysical data available, the Vepsian rocks are restricted to a depression, 150 km by 100 km in size, which can be referred to as the South Onega L. Depression. Another depression was located by seismic data southeast of the former, and is believed to be filled with Vepsian rocks, too, (see the respective Figure 1). The maximum thickness of the Vepsian rocks in the middle of the South Onega Depression is >2000 m [*Galdobina and Mikhailov,* 1989].

[12] *Leonov et al.* [1995] combined this rock complex with the underlying sequences of Yatulian diabase, cross-bedded variegated quartzite, sandstone, and white quartzite, mainly developed in the area of the Segozero Lake and along the northern margin of Onega Lake. The Yatulian rocks of this sequence show several structural unconformities, the largest of which being observed either at the top or at the bottom of the Vepsian rocks. The Yatulian rocks are relatively flat, being complicated by a system of subvertical faults.

[13] The presence of the unconformity at the base of the Vepsian rocks and the fairly contrasting differences in the lithology of the Yatulian and Vepsian rocks suggest that here we deal with two different rock complexes: the Yatulian rocks belonging to the protoplatform sedimentary cover, and the Vepsian rocks of the quasiplatform cover.

[14] The Swedish geologists rank the Dala Series and its analogs (Smoland and Omol series) as sub-Jotnian ones. The Dala Series consists mainly of acid effusive rocks (quartz porphyry and rhyolite) and tuff with conglomerate and quartz sandstone interbeds. These rock sequences, as thick as 2000 m, rest on the rapakivi-like granites of the Vermland Pluton (see Figure 1). The youngest generations of the rapakivi granites cut the rocks of the Dala Series. The radioisotopic age of the latter was estimated to be 1700 Ma [*Nikolaev,* 1999].

[15] In the other areas of the Baltic Shield and in the adjacent areas of the Baltic Syneclise, ranked as sub-Jotnian are the rocks of the Hogland Series [*Raukas and Hyuvarinen,* 1992]. The most complete and well studied sequence of the latter is exposed in Suursaar Island located in the central part of the Gulf of Finland. Here, the rocks of the crystalline basement are overlain by quartzite conglomerate members (less than 0.15 m thick), diabase porphyrite (up to 20 m thick), and quartz porphyry (up to 100 m thick). These rocks dip to the east in the monoclinal manner at the angles of 5° to 29° [*Raukas and Hyuvarinen,* 1992]. The isotope age of the volcanic rocks was found using the K-Ar dating to vary from 1580 to 1670 million years [*Puura,* 1974].

[16] The Undva Hole drilled in the Saaremaa Island exposed the rocks of the Hogland Series in the depth interval of 391–441.3 m. Its lower sequence is composed of diabase porphyry, the upper one, of quartz porphyry. The Pavilosta and Vergale holes drilled in the southwest of Latvia penetrated the quartz porphyry over a depth of 5 m.

[17] The potential age analogs of the Hogland rock series are the thin (less than 23 m) volcanic rocks (basalt and tuff) and terrigenous rocks (breccias, conglomerates, and sandstones) of the Veivirzha rock sequence developed in the west of Lithuania [*Stirpeika,* 1987].

[18] The rocks of the sub-Iotnian and Hogland series tend to be associated with large plutonic rock bodies of rapakivi granite, anorthosite, and gabbro-norite. The igneous rocks are developed in the western part of the platform (see Figure 1) and had been emplaced by the multiphase intrusions of differentiated magma into the upper layers of the Earth's crust. The isotope ages, obtained for the plutonic rocks, fit in the range of 1700–1500 Ma [*Semikhatov,*1974].

[19] In the Ukrainian Shield, the oldest undislocated rocks are the rocks of the Pugachev Series, filling the Belokorovichi graben-syncline of the nearly meridional strike, 30×7 km in

size. This structural feature is restricted to the gneiss, igneous rocks , and granites of the Kirovograd-Zhitomir Early Proterozoic rock complex. Its eastern side borders, locally along faults, the Korosten Pluton composed of rapakivi granite, anorthosite, and gabbro norite.

[20] The Pugachev Series consists of the Belokorovichi and Ozeryanka formations. The rocks of the former have the maximum thickness of 500 m. Its lower part is composed of interbedded metasandstones and metargillites (phyllite-like shales), the upper part being a monotonous sequence of grayish-pink quartz sandstones. The Ozeryanka Formation occupies the central part of this structural feature. Its thickness may be as large as 700 m [*Drannik,* 1985]. It is composed of interlayered greenish gray metasiltstones. The lower part of this formation includes occasional diabase porphyrite sheets, as thick as 25 m. Locally encountered were the veins of the rapakivi-like granite of the Korosten Complex, which cut the shale of the Ozeryanka Formation [*Drannik,* 1985].

[21] As reported by *Verkhoglyad,* [1995], the oldest anorthosite of the Korosten Pluton was dated 1794±6.7 Ma, the youngest granite-porphyry dikes being 1735 Ma old. The latest stratigraphic map of the Precambrian rocks of the Ukrainian Shield shows the rocks of the Pugachev Series and those of the Korosten Complex placed at the same age level of 1700–1800 Ma.

[22] To sum up, the Vepsian, Hoglandian, and sub-Jotnian rocks, as well as those of the Pugachev Series, can be ranked, in terms of their ages, as the Late Paleoproterozoic (Staterian) rocks. Proceeding from the fact that the rock complexes described are usually separated from the overlying rocks, also classified as belonging to the quasiplatform cover, by angular and stratigraphic unconformities and differ in terms of their lithology, metamorphism, and dislocation, they can be identified as the lower complex of the quasiplatform rock cover.

[23] Proceeding from their geologic positions and radioisotope datings, the younger rocks of the platform cover are the Jotnian rocks of the Baltic Shield and Baltic Syneclise, the Ovruch Series of the Ukrainian Shield, and their age and rock analogs in the Belorussian Anteclise.

[24] The Jotnian rocks rest either on the weathered surfaces of the rapakivi granites and on the sub-Jotnian rocks or in their vicinities. They are most widely developed in the Tryusil-Dala region on both sides of the frontier between Sweden and Norway (see Figure 1), where they are represented by a sequence, as thick as 800 m, of quartz and greywacke sandstones and conglomerates which lie on the weathered surfaces of the sub-Jotnian rocks and rapakivi granites. The sandstone sequence includes two sheets of the Eiye effusive diabase sheets, 75–90 m thick. The isotope age of the effusive rocks was found to be 1300–1400 million years [*Konopleva and Tikhomirova,* 1977]. The Jotnian and underlying rocks are cut by basic intrusions (Osbu dolerite). On the whole, the Jotnian rocks are either horizontal or dip slightly to the east, producing a shallow depression [*Holtedal,*1957].

[25] In other areas of the region the Jotnian rocks were found either in narrow grabens or in wider graben-synclines. The Jotnian rocks of the Satakunta Graben in the southwest of Finland are composed of arcose sandstones and conglomerates, which are cut by olivine diabase dikes dated 1250–1270 Ma. The thickness of the Jotnian rocks, cut by boreholes, amounts to 617 m, the interpretation of the aeromagnetic data showed it to be as large as 1200–1600 m [*Raukas and Hyuvarinen,* 1992]. It is supposed that these rocks were deposited at the expense of the erosion of the basement metamorphic rocks, rather than of the rocks of the nearest Laitila rapakivi granite massif, which in Jotnian time resided below the erosion surface [*Raukas and Hyuvarinen,* 1992].

[26] Compositionally similar are the Jotnian rocks in the Mukhos Graben, as thick as 1000 m, in the Evle Graben, and in some other grabens.

[27] The gravity measurements and the results obtained from borehole measurements in scarce holes suggest the wide development of Jotnian rocks in the central part of the Baltic Sea, where the South Bothnian isometric and Cedra-Quarken and Gotska-Sanden elongated graben-synclines were mapped (See Figure 1). The graben-synclines are supposed to have an asymmetric structure, one of their wings having been lowered by faults, the other being a gentle monocline [*Raukas and Hyuvarinen,* 1992]. The thickness of the Jotnian rock sequences in the South Bothnian graben-syncline may be larger than 1000 m [*Ahlberg,* 1986], and that in the Gotska-Sanden graben syncline being 900 m [*Ryka,* 1973].

[28] Also dated as Jotnian are the rocks that are developed locally in the central area of the Baltic Syneclize (Western Lithuania). These are the quartz sandstone and siltstone (less than 14 m thick) of the Baublyai rock sequence [*Stirpeika,* 1987] and also the quartzite, quartz sandstone, and diabase, crossed to depths of 12 m to 56 m by four holes drilled in the area of the Mazur buried protrusion of the Belorussian Anteclise in northeastern Poland [*Ryka,* 1973].

[29] In the northern part of the Korosten Pluton the weathered surface of rapakivi granites is overlain by the rocks of the Ovruch Series, restricted to the Ovruch graben-syncline [*Velikoslavinskii et al.,* 1978; *Lunko et al.,* 1971]. This structural feature shows a latitudinal strike and measures 100×25 km in size. The Ovruch Series consists of the Zbrankovo (lower) and Tolkachevo formations. The former is composed of interbedded effusive rocks (diabase, quartz porphyry, and trachyandesite porphyrite) and terrigenous rocks (conglomerates and volcanomictic sandstone). Its thickness is as large as 350 m. The Tolkachevo Formation is almost wholly composed of red quartz sandstone with interbeds (<2 m thick) of pyrophyllite schists. Its maximum thickness is 930 m. Most of the radioisotope datings available for the rocks of the Ovruch Series fit in the range of 1370–1500 million years [*Shcherbak et al.,* 1985].

[30] In the eastern part of the Belorussian Anteclise (buried Bobruisk High), several holes exposed the rocks of the Bobruisk Series. This series includes the rocks of the Luchkov Formation (quartz porphyry, 26 m thick) and those of the Myshkovichi Formation (quartzite sandstone interbedded by pyrophyllite schist layers). The rocks of this formation were also exposed by several holes drilled in the northern part of the Pripyat Trough. The maximum thickness of this formation is 23 m. The rocks of the Luchkov

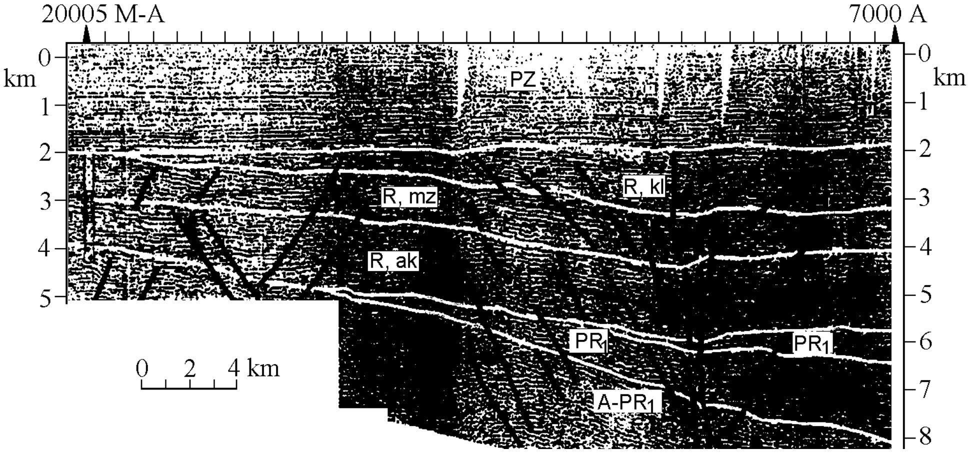

Figure 2. Stratified CDP seismic section crossing the holes 20005-MA to 7000-A at the western side of the Kama-Belsk aulacogen [*Kazantsev et al.,* 2002].

Formation are believed to rest on those of the Myshkovichi Formation, yet, their contact had not been exposed by the holes. This view is based on the similarity of the rocks of the Bobruisk and Ovruch series, where the volcanic rocks underlie the terrigenous ones.

[31] The isotope (K-Ar) datings of the Bobruisk rocks fit in the age range of 1290±20 Ma to 1450±20 Ma [*Aizberg et al.,* 2002; *Makhnach et al.,* 2001]. These rocks are restricted to the small Bobruisk graben-syncline ranging between 80 km and 40 km in size. A similar depression, known as the Krasnopolskaya one, is inferred from geophysical data to be located on the western slope of the Voronezh Anteclise.

[32] The Jotnian rocks of the Ovruch Series, and their analogs, can be dated Mesoproterozoic (Early Riphean) and interpreted as the upper rocks of the quasiplatform sedimentary cover of the East European Platform.

2.2. The Central and Northern Segments of the Platform

[33] Several holes drilled in the northern part of the Russian Platform (e.g., Konosha and Krestsy-2 holes) penetrated the quartz sandstone and shale similar to the Vepsian rocks. The diabase and diabase-porphyry dikes, injected into the sedimentary rocks, showed the age of ∼1300 million years.

[34] The recent seismic CDP profiles, recorded in the western part of the Moscow Syneclise, showed that the top of the crystalline basement resided 500–1000 m deeper than had been believed earlier. The new seismic data suggested that a sequence of supposedly sedimentary and igneous rocks with V_p = 4500 m s^{-1} resided between the cata- and orthoplatform sediments and the crystalline basement. This suggested that this sequence included both carbonate and igneous rocks, which was confirmed by the results obtained from single holes (marble in Rybinskaya-2 Hole and volcanic rocks in Molokovskaya P-1 Hole and Krestsy-2 Hole). Proceeding from the microfossils found in these rocks [*Nikolaev,* 1999], they can be identified as Lower and, partially, Middle Riphean. The area of their development coincides mainly with the western part of the Middle Russia aulacogen. It cannot be ruled out that some of these rock sequences represent the cataplatform volcanic sediments and sedimentary rocks of the Dalslandian (Middle Riphean) structural complex. They are as thick as 430 m in the Krestsy-1 and Krestsy-2 holes and >1100 m thick in the Pavlov Posad Hole (Moscow suburb graben) [*Aizberg et al.,* 2002].

[35] In the middle of the Moscow Syneclise, seismic refraction shooting and CDP measurements located a layer with seismic velocities ranging from 5.4 km sec^{-1} and 6.0 km s^{-1}. This layer is 1.5 km to 2.0 km thick and seems to be composed of Lower and, partially, Middle Riphean sedimentary and igneous rocks [*Nikolaev,* 1999].

[36] As follows from the deep seismic sounding data obtained in the area of the Dnieper-Donets aulacogen, the typical sedimentary rocks are underlain by a layer, as thick as 10–12 km. It is bounded by a K_0 surface (V_r = 5.7–5.9 km s^{-1}) at the top, and by a K_1 surface (V_r = 5.8–6.2 km s^{-1}) at the bottom. This rock sequence is restricted to a graben-type structural feature. It seems to be composed, at least in its lower part, 1–2 km thick, of poorly metamorphozed sedimentary and volcanic rocks of Early Riphean age.

[37] As follows from the data, afforded kindly by the Spetsgeofizika Company, the similar rock sequences were recorded by the CDP reflection profiles also in the area of the Pachelma Aulacogen, where they fill the most depressed areas of this structural feature and are as thick as 1 km.

2.3. The Eastern Segment of the East European Platform

[38] The time sections derived from CDP reflection shooting, carried out in the eastern part of the platform (Kama-Belsk Trough), recorded a horizontally layered rock sequence at the base of the platform sedimentary cover, which was found to be similar, in terms of the velocity and density of the rocks, to the intermediate rock complex mapped in the central areas of the platform. Geologically, this rock sequence is composed of interbedded, poorly metamorphosed, sedimentary and igneous rocks (Figure 2). The pro-

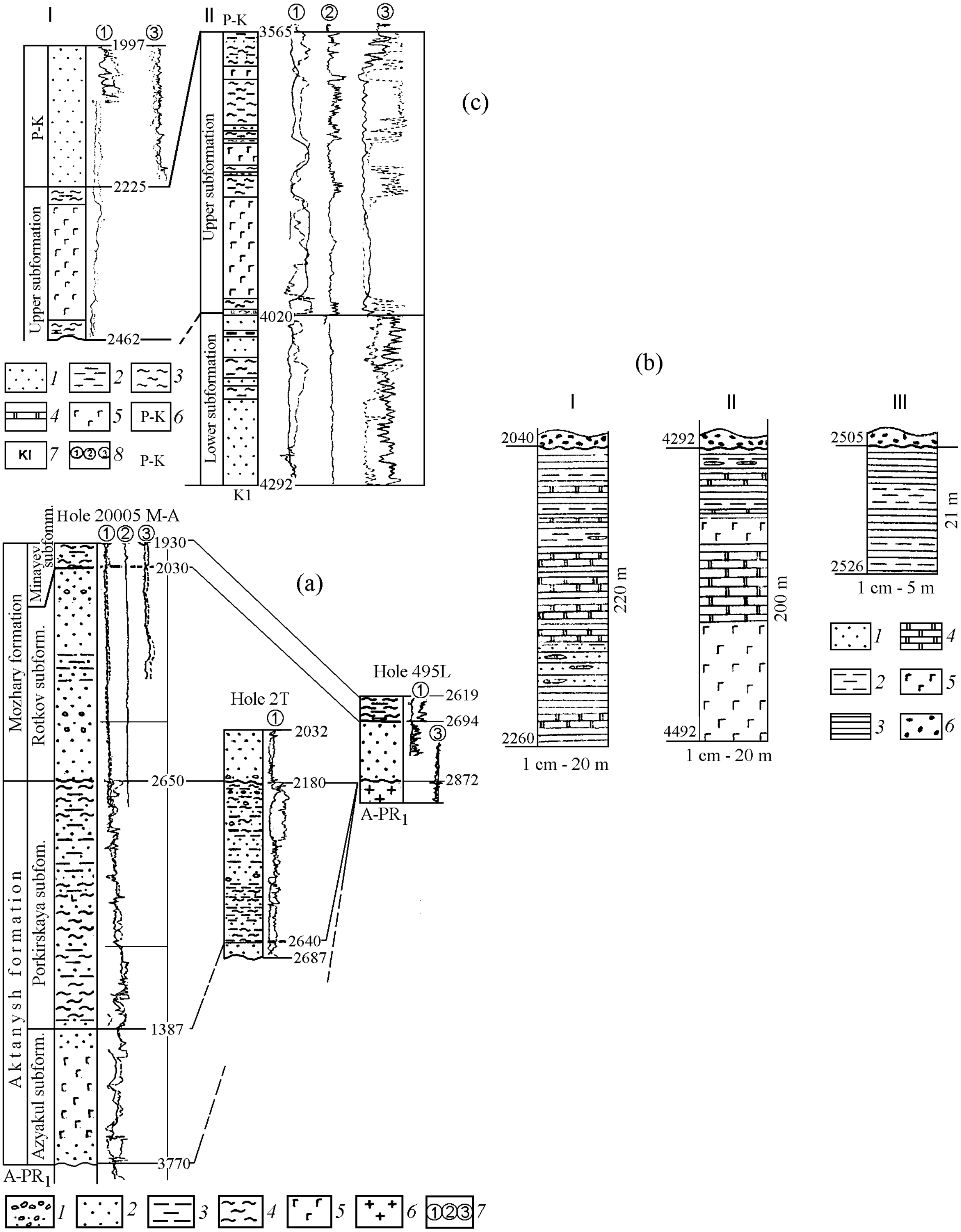

Figure 3. Correlation of the Early Riphean rocks of the Bashkiriya Platform, exposed by holes [*Romanov and Isherskaya,* 2001]. (See legend on the next page).

file depicted in this figure and the other profiles, showed an angular unconformity between the lowest Early Riphean rocks (Aktanysh and Mozhary formations) and the Middle Riphean rocks (Kaltasa Formation).

[39] The deepest holes that exposed the study rocks in the central and western parts of the Kama-Belsk Trough, namely, the Nadezhdino-27, Arlan-7000, Or'ebash-82, to name but a few, allow one to date the rocks Early Riphean [*Kazantsev et al.,* 2002].

[40] As follows from the data reported by *Romanov and Isherskaya* [2001], the Lower Riphean rocks are developed widely in the Kama-Belsk Trough, where they are as thick as 9 km in the zone where the rocks of this complex contact the folded rocks of the Ural Mountains. These are terrigenous and carbonate rocks enclosing numerous intrusive bodies of basic igneous rocks.

[41] The sequence of the Lower Riphean rocks showed a distinct three-member structure (Figure 3). Its lower part is represented by two Aktanysh and Mozhary formations, which are interpreted as the large sedimentation rhythms of the transgression type. The rock sequences of these formations begin with coarse clastic rocks (sandstones interlayered by gravelstones) and end with siltstones and argillites. Basalt flows, as thick as 16 m, were found in the lower part of the Aktanysh Formation. The thickness of this part of the Early Riphean rock sequence grows toward the trough axis to measure 2–2.5 km and amounts to 3.5 km in the zone of junction with the Ural.

[42] The intermediate part of the Lower Riphean rock sequence consists wholly of carbonate rocks (dolomite and limestone) and carbonate-argillaceous rocks (marl and argillite) of the Kaltasa Formation. They are as thick as 3.0–3.5 km in the axial part of the trough, their thickness growing to 4.0–5.0 km in the zone where the trough joins the Ural Mts.

[43] The upper part of this rock sequence is represented by the Nadezhdian Formation (terrigenous rocks with carbonate interbeds in the top), 1.5 km to 2.0 km thick, being as thick as 3.0 km in the most eastern areas.

[44] The Lower Riphean rocks are intruded everywhere by numerous basic rock bodies. Their absolute ages, obtained mainly by the K-Ar method, fit in the range of the Early Riphean time (1542±18 to 1310 Ma). Chemical analyses were made of clay minerals, authigenic glauconite, and also of basic rocks, such as basalt and gabbro-diabase [*Romanov and Isherskaya,* 2001].

[45] To sum up, in the west of the East European Platform the quasiplatform sedimentary rocks have been subdivided into two sequences: the lower (Staterian) sequence and the upper (Early Riphean) sequence. Both of them are represented by volcanic and terrigenous rocks and are restricted to layered plutons. In the east of the platform the Lower Riphean rocks fill the extensive Kama-Belsk Trough. In terms of their age and geophysical characteristics, they resemble the younger quasiplatform sediments of the western regions, yet, the rhythmic type of their bedding and the fact that they are restricted to the large trough, make them to be similar to the younger cataplatform rocks filling the Middle-Late Riphean aulacogens.

[46] In the central part of the East European Platform the quasiplatform rock cover seems to have been conserved under the younger Middle-Late Riphean aulacogens (Mid-Russian, Pachelma, and others) and, as follows from its geophysical data, has a composition, similar to that of the Early Riphean rocks of the Kama-Belsk Trough.

3. Paleotectonic Conditions of the Accumulation of Quasiplatform Sediments

[47] The time of the quasiplatform sediment accumulation can be subdivided into two stages: Staterian (1750–1600 million years) and Early Riphean (1600–1300 million years), during which the rocks of the lower and upper subtypes accumulated.

[48] The lower complex of the quasiplatform sediments accumulated in different conditions depending on the predominant type of the rocks. The Vepsian rocks and those of the Pugachev Series, represented mainly by terrigenous rocks and, partly, by the rocks of volcanic origin, accumulated, in part, in isolated depressions, which had been formed in the west of the craton after the Svecofennian-Kareian consolidation of the continental crust. On the other hand, some of the structural features (especially those east of the craton, for example, the Orsha Basin) are the remnants of the deeper and larger depressions which had been filled by molassa-like rocks, namely, by the products of the erosion of some orogenic structures. This is proved by the high limitation of their lithologic varieties, the absence of coastal rock facies,

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(a) The rocks of the Aktanysh and Mozhary formations exposed by the Menzelin-Aktanysh-20005, Tyuryushevo-2, and Leonidovka-495 holes. (1) Conglomerate and gravelstone, (2) sandstone, (3) siltstone, (4) argillite, (5) gabbro diabase, (6) basement granite gneiss; (7) well-logging diagrams: (1) electric logging, (2) caliper logging, and (3) radiometric logging.
(b) The rocks of the upper Kaltasa Formation exposed by the Oriebash-18 hole (I), the Asly-Kul-4 hole (II), and the Leonidovka-495 (III). (1) sandstone, (2) siltstone, (3) argillite, (4) dolomite, (5) gabbro diabase, (6) the basal member of the Nadezhdian Formation.
(c) The rocks of the Nadezhdino Formation exposed by the Nadezhdino-27 Hole (I) and the Asly-Kul Hole (II). (1) sandstone, (2) siltstone, (3) argillite, (4) dolomite, (5) gabbro-diabase, (6) Middle Riphean Novokipchak Formation, (7) Lower Riphean Kaltasa Formation, (8) well-logging diagrams: (1) electric logging, (2) caliper logging, and (3) radiometric logging.

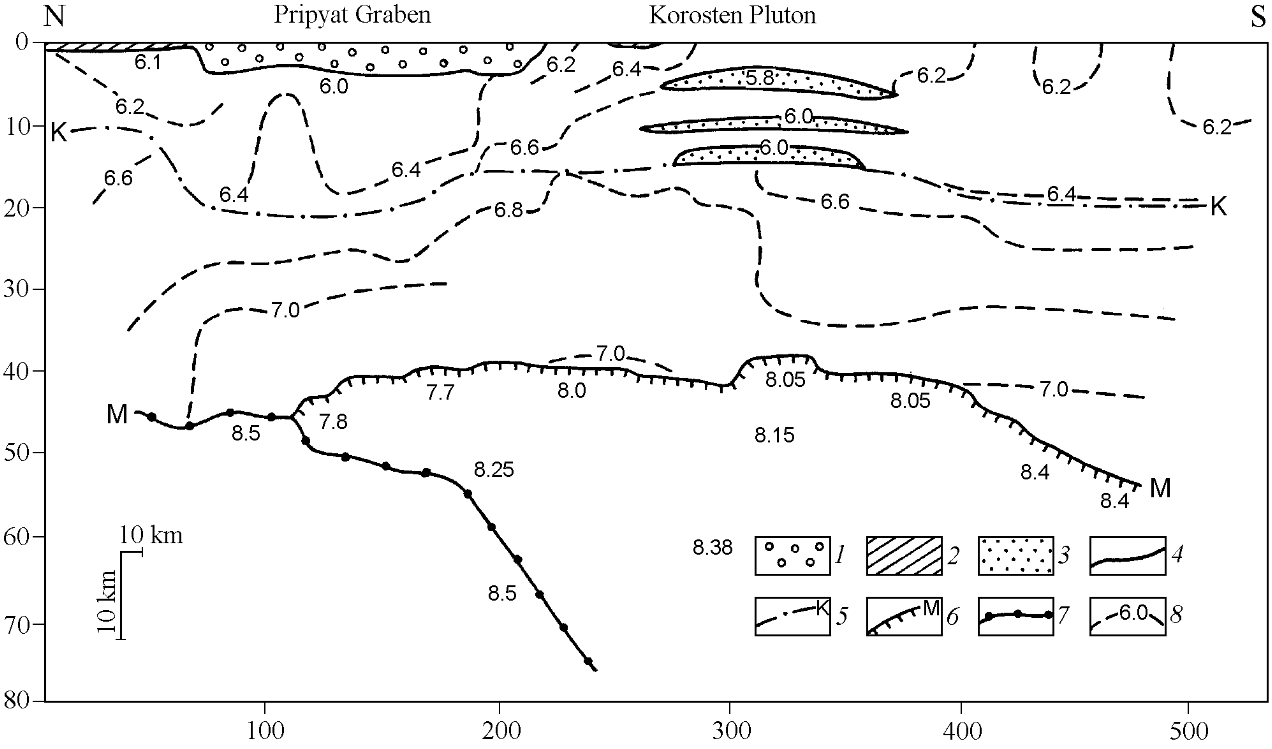

Figure 4. Velocity model of the Earth crust and upper mantle along the EUROBRIDGE-97 Geotransect, after [*Ilchenko,* 2002]: (1) the Paleozoic sediments of the Pripyat Graben; (2) Riphean-Vendian sediments; (3) low-velocity layers in the consolidated crust; (4–6) seismic: (4) the top of the crystalline basement, (5) Conrad discontinuity, (6) Moho discontinuity and the top of the "Sarmatian" mantle, (7) the top of the "Phenoscandian" mantle, (8) velocity contour lines in km s^{-1}. The Sarmatian and Phenoscandian mantles were mapped conventionally using their positions under the crustal blocks of Sarmatia and Phenoscandia.

and the similarity of their structure and lithology to the synchronous rocks in the more eastern areas [*Aizberg et al.,* 2002; *Makhnach et al.,* 2001; etc.].

[49] As regards the accumulation of the sub-Jotnian rocks in Sweden, it seems to have been associated with the final stage of the evolution of the trans-Scandinavian volcano-plutonic belt [*Ahlberg,* 1986; *Floden,* 1980]. The rocks of this type (quartz porphyry with conglomerate interbeds) accumulated at the very end of the belt formation, when the plutonic bodies had already been brought to the ground surface because of the intensive rising and erosion of the upper crust. The topographical lows were filled by coarse volcanic rocks along with coarse terrigenous materials.

[50] It cannot be ruled out that the rocks of the Hogland Series and the similar quartz porphyry, exposed southwest of the Riga Pluton, accumulated under the same conditions [*Stirpeika,* 1987].

[51] The upper complex of the quasiplatform sedimentary cover, composed of Lower, in places, Middle Riphean rocks, also mainly tends to be located in the areas of plutonic bodies of rapakivi granite and associated rocks, although these sedimentary rocks accumulated after their intrusion.

[52] To derive a potential model for the structural formation of this subtype of the sedimentary cover, we used the new geophysical data obtained in the north of the Ukrainian Shield and in some of the adjacent territories. This area includes the large Korosten Pluton, composed of anorthosite and rapakivi granite, and the Ovruch graben-syncline located in its northern periphery. Proceeding from the general pattern of the crustal structure of this pluton, obtained from the results of the deep seismic sounding profiles recorded along the "Eurobridge-97" Geotransect [*Ilchenko,* 2002], it can be concluded that the crust underlying it is composed mainly of mafic rocks (Figure 4).

[53] The Moho discontinuity under the pluton was recorded to be as shallow as 40 km. The crustal basement includes a body with high compressional-wave velocities (6.8 km s^{-1} to 7.0 km s^{-1}), up to 20 km thick and about 150 km in diameter, its most elevated portion residing somewhat north of the pluton, at the boundary between the Ukrainian Shield and the Pripyat Trough. Another high-velocity body of smaller diameter (about 90 km) with longitudinal seismic velocities ranging from 6.4 km s^{-1} in the top to 6.8 km s^{-1} in the bottom was recorded above it. This body was found to be highly asymmetric, nearly outcropping in the south, and plunging to a depth of 12–15 km in the north.

[54] The Early Rhyphean time seems to have witnessed the processes of the viscoelastic flow of the not finally crys-

tallized igneous material in the eastern direction. As a result of dynamic metamorphism, the basic rocks might have been differentiated into the anorthosite and gabbro-norite components.

[55] The high-temperature lateral flow of the basic material involved the gneiss complexes of the country rocks, causing their partial metamorphism in the contact zones. However, some of the gneiss layers, as thick as 2–3 km, might have survived as slabs with the lower velocities of longitudinal waves (see Figure 4).

[56] The southward flow of the crustal material in the southern direction and its compaction might cause the substantial subsidence of the crust above the northern and central parts of the initial magma chamber. This process was accompanied first by faulting, which resulted in the pressure decline and, as a consequence, by the regeneration of the cooling magma chambers and the partial melting of the rocks.

[57] Therefore, acid and intermediate magma chambers might be formed at shallow depths. The flow of this magma to the ground surface resulted in the devastation of the magma chambers and in the subsequent sagging of the crust. This activity produced a large depression which embraced not only the northern part of the Korosten Pluton, but also the significant territories bordering it in the north (the southeastern part of Belorussia). The slow subsidence that followed the early volcanic phase resulted in the accumulation of a thick monotonous sequence of quartz sand. At the present time, only some fragments of this sedimentary basin remained in the form of the Ovruch and Bobruisk series and their analogs.

[58] It appears that the mechanism of the lateral movement of not fully crystallized magmatic rock masses was responsible for the formation of some other Early Riphean depressions in the area of the Baltic Shield under the Baltic Sea Area. These depressions are restricted either to the northwestern periphery of the pluton (Dala Syncline in the Vermland Pluton), or to the areas north and northwest of the latter (see Figure 1).

[59] In his recent publication *Leonov* [2001], proved that after its consolidation, the crust remains to be mobile and is subject to structural transformations, associated with volumetric-plastic, brittle-plastic, and cataclastic flow, for which he used the term “rheid” deformation. He emphasized that the formation of sedimentary basins in many regions of the world had been associated with this type of deformation. It appears that this mechanism was responsible for the formation the lower rock complexes in the lower quasiplatform sediments in the East European Platform.

[60] The Kama-Belsk submeridional trough was being formed in the east of the East-European Platform during the Riphean time. This trough can be classified as a large structural feature associated with the subsidence of the platform margin at its boundary with the Riphean Paleoural Ocean [*Kuznetsov et al.,* 2004]. The Lower Riphean rock sequence with the maximum thickness of 8 km shows the distinct structure of a large sedimentation cycle. Its lower and upper parts are composed mostly of terrigenous rocks, its middle interval consisting mainly of argillaceous-carbonate deposits.

[61] At the same time the accumulation of the thick Lower Riphean sediments was interrupted by short-time rises and also by the epochs of compression. This is proved by angular unconformities between some individual segments of the rock sequence (Figure 5). The relatively gentle structural elements of the Aktanysh and Mozhary time are replaced abruptly by the structural features of the Kaltasa time. At the latest stage (Nadezhdian time) a gentle basin was formed, its sides being complicated by small local highs.

[62] It is not unlikely that some depression of the syneclise type existed in that time in the central part of the East European Platform, where volcanic and sedimentary rock sequences might have accumulated. Their fragments might have been conserved from erosion under the Late Riphean-Early Vendian aulacogens.

4. Conclusion

[63] The quasi-platform sedimentary cover of the East European Platform has a specific structure. It is represented by poorly dislocated volcanic and sedimentary rock sequences which accumulated over a long period of time: from the Paleoproterozoic (Staterian) to the middle of the Mesoproterozoic (Early Riphean).

[64] In the west, the quasi-platform sediments of the East-European Platform are combined in terms of space (restricted to the anorthosite and rapakivi-granite plutons) and in terms of paleogeodynamics, having accumulated in the structural features which had been formed as a result of the lateral movements of the plutonic material.

[65] The quasi-platform type of the sedimentary cover can be subdivided into two, lower and upper, subtypes. The rock material of the former accumulated at the end of the Paleoproterozoic (Staterian), simultaneously with the accumulation of the anorthosite-rapakivi granite formation, and those of the latter, during the early half of the Meso-Proterozoic (Early Riphean) time, after the cratonization of the rock material.

[66] In our opinion, the first subtype of the sedimentary cover includes the Vepsian rocks of Karelia, the sub-Jotnian rocks of Sweden, the Pugachev Series of the Ukraine, and, possibly, the Hogland rock series of the Baltic region.

[67] The upper rock complex of the quasi-platform rocks is represented by the Jotnian rocks of the Baltic, Sweden, and Finland regions, by the Ovruch Series of Ukraine, and Bobruisk Series of Belorussian. The intermediate rocks located by seismic data under the middle of the Moscow Syneclise, in the axial zone of the Donets-Dnieper Aulacogen, and in some other areas, are yet to be dated.

[68] In the east of the East European Platform, the rocks having the same age as the quasiplatform sediments of the western regions are developed in the Kama-Belsk Trough and in some other structural features. They are represented by a sequence of terrigenous and carbonate rocks up to 9 km thick. In terms of their velocities and densities, they resemble the rocks of the intermediate rock complex of the Central East European Platform.

[69] It should be noted that in paleotectonic sense the accumulation of the lower quasiplatform sediments took place

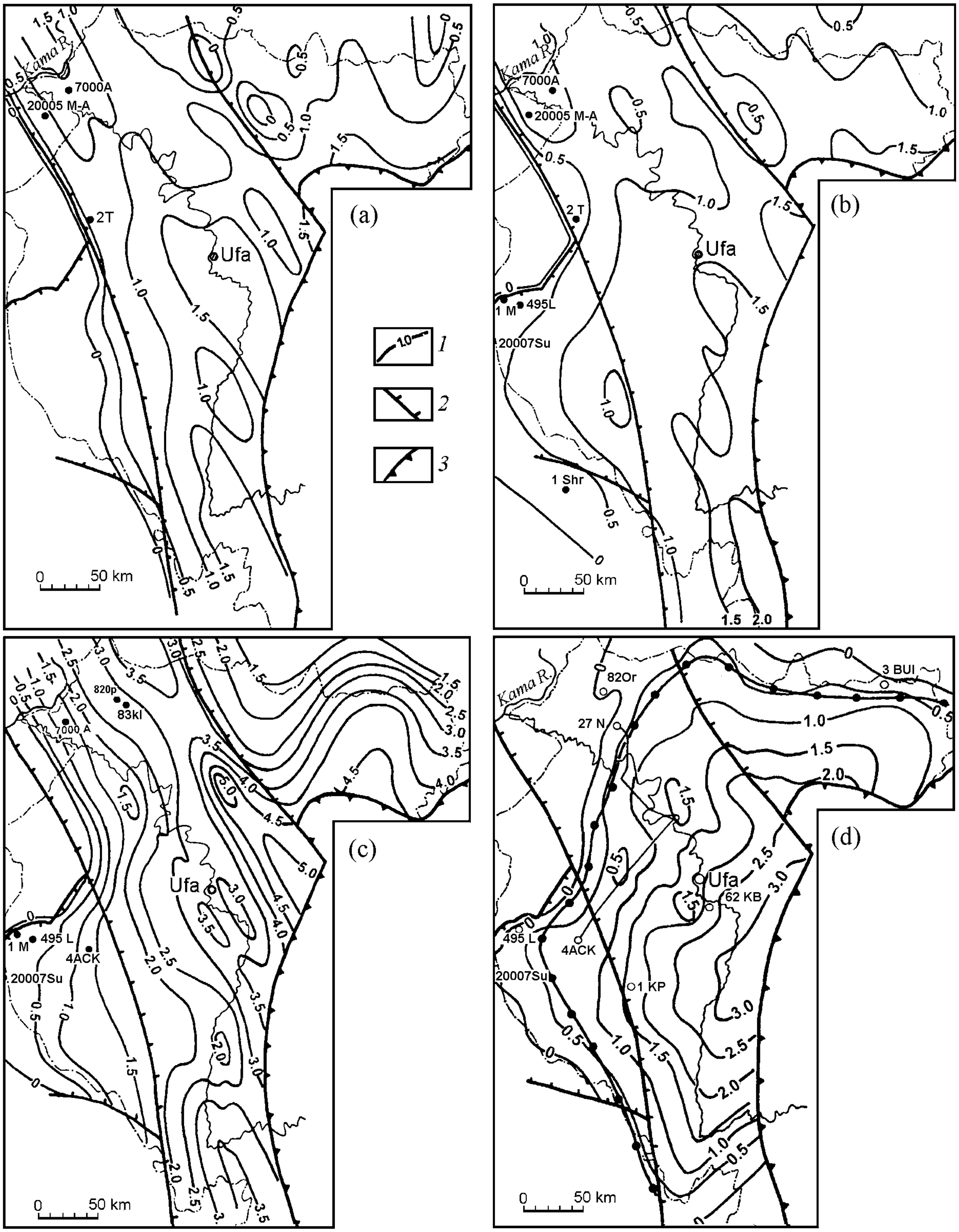

Figure 5. Isopach maps for different Early Riphean rock formations of the Ural region [after *Romanov and Isherskaya,* 2001]: (A) Aktanysh Formation, (B) Mozhary Formation, (C) Kaltasa Formation, and (D) Nadezhdian Formation. 1 – isopach line, km; 2 – basement faults; 3 – the western boundary of the Ural Mountains

during the final stages of the structural evolution of the basement. During the Staterian time depressions were formed in the zones of the Svecofennian-Karelian reactivation, where molassa-type material accumulated (Vepsian Pugachev rock series and its analogs). At the same time, or somewhat later, high plutonic activity developed in the west of the East European Platform (EEP). This process was accompanied locally by volcanic activity with acid lava flows.

[70] During the early half of the Meso-Proterozoic (Early Riphean) time, depressions of various types (graben-synclines and isometric basins) began to form as a result of the lateral displacement of plutonic material, mainly along the northern peripheries of the plutons. It cannot be ruled out that these basins had occupied significantly larger areas, compared to those occupied by their fragments at the present time.

[71] In the eastern EEP segment, the Kama-Belsk basin developed, which can be interpreted as a large structural feature developed in the zone of pericratonic subsidence. It is likely that a large depression of the protosyneclise type might develop at that time in the East European Platform.

[72] Taking into account the formational and geographic association of the lower and upper rock complexes, they can be interpreted as one structural stage, in spite of a structural unconformity between them. In the central and eastern segments of the platform, the quasiplatform sedimentary cover has been mapped, because of its great depth, using the geophysical data alone, yet, even in this case no boundary could be traced between the lower and upper rock complexes.

[73] Having analyzed all data available for the western, central, and eastern segments of the sedimentary cover in the western, central, and eastern parts of the East European Platform, we found that each of these segments had its own geodynamic environment. In the west, the latter was controlled by a long-evolving uplifting activity, which resulted in the formation of small structural features with a thin quasiplatform sedimentary cover, subject to constant erosion. In the central part, the quasiplatform sediments apparently covered, as a mantle, the largest area of the territory, yet, shear stress existed, which controlled the formation of aulacogens in Middle-Late Riphean time. Some fragments of the quasiplatform sedimentary cover were preserved in the central, most depressed parts of the aulacogens. Yet, there are some individual exceptions, for example, the small area underlain by the upper quasi-platform sedimentary rocks in the area of the Konosha Hole. Finally, in the east the accumulation of the quasi-platform sediments was controlled highly by the processes that operated in the adjacent paleo-Ural Ocean (pericratonic subsidence). To conclude, in spite of the varying geodynamic conditions, the same age, the similar lithology of the rocks, and the magmatic activity of some or other type allow one to assume that the whole complex of the quasiplatform sedimentary rocks reflects the same evolution period of the East European evolution.

[74] **Acknowledgments.** This work was supported by the Belorussian Foundation for Basic Research, Project no. X-02P-027, and by the Russian Foundation for Basic Research, Project no. 02-05-81002.Bel.2002a.

References

Ahlberg, P. (1986), Den Svenska kontinentalsockelns berggrund, *Sven. Geol. Unders. Raporter Och Meddelanden, 47,* 101.

Aizberg, P. E., N. V. Aksamentova, and N. D. Belonin (2002), *The Geology and Oil and Gas Prospects of the Precambrian Rocks in the East European Platform* (in Russian), 391 pp., Nedra, St. Petersburg.

Bibikova, E. V., T. I. Kirnozova, and Yu. I. Lazarev (1990), The U-Pb isotopic age of the Vepsian rocks in Karelia, *Proc. Akad. Nauk* (in Russian), *310*(1), 189.

Drannik, A. S. (1985), Pugachev rock series, in *Precambrian Stratigraphic Rock Sequences in the Ukrainian Shield* (in Ukrainian), p. 150, Naukova Dumka, Kiev.

Esipchuk, K. E., M. P. Shcherbak, and E. B. Glevatskii (1999), Verified Precambrian Stratigraphy in the Ukrainian Shield, *Mineral. J.* (in Ukraine), *21*(1), 5.

Floden, T. (1980), Seismic stratigraphy and bedrock geology of the Central Baltic region, *Stockholm Contrib. Geol., 35,* 1.

Galdobina, L. P., and E. M. Mikhailov (1989), Vepsian, in *Stratigraphy of the USSR: Early Precambrian: European Part,* p. 158, Nedra, Moscow.

Garetskii, R. G., (Ed.) (1976), *The Tectonics of Belorussia,* 182 pp., Science and Technology, Minsk.

Garetskii, R. G., (Ed.) (1983), *Paleotectonics of Belorussia,* 182 pp., Science and Technology, Minsk.

Garetskii, R. G., (Ed.) (2001), *The Belorussian Tectonosphere: Crustal Structure and Useful Minerals,* 133 pp., Science and Technology, Minsk.

Holtedal, U. (1957), *Geology of Norway,* 212 pp., Foreign Literature Publishing House, Moscow.

Ilchenko, T. V. (2002), The results of DSS profiling along the EUROBRIDGE-97 Geotransect, *Geophys. J., 24*(3), 36.

Kazantsev, Yu. V., V. A. Romanov, and Sh. A. Mustafin (2002), *The Structure of the Neftekamsk-Artinsk Zone in the Eastern Margin of the East-European Platform,* 30 pp., Bashkirian Academy of Science, Ufa.

Konopleva, N. G., and N. Ya. Tikhomirova (1977), Correlation of Riphean red beds in the northwest of the East European Platform, in *The Geological Position of the Northwestern Margin of the Russian Platform from New Geostructural Data,* p. 27, Nedra, Moscow.

Kuznetsov, N. B., A. A. Soboleva, and O. V. Udoratina (2004), The formation of the protouralides and timanides collision belt, in *The Geology and Mineral Resources of Northeast Russia,* vol. II, p. 21, Geoprint, Syktyvkar.

Leonov, M. G. (2001), Continental basement tectonics and the vertical accretion of the consolidated crust, in *Fundamental Problems of Tectonics,* p. 91, Nauchnyi Mir, Moscow.

Leonov, M. G., S. Yu. Kolodyazhnyi, and M. L. Somin (1995), Tectonic flow structures in the deposits of the protoplatform cover of the Karian Massif (Baltic Shield), *Bull. Moscow Soc. Nature Researchers, Ser. Geol., 70*(3), 20.

Lunko, V. F., A. S. Drannik, A. G. Rolik, and S. V. Metalidi (1971), The basic features of the geological structure and metallogeny in the northwestern part of the Ukrainian Shield, in *The Problems of the Petrology and Mineralization of the Crystalline Basement of Belorussia and Adjacent Regions,* p. 286, Science and Technology, Minsk.

Makhnach, A. S., R. G. Garetskii, and A. V. Matveev, (Eds.), (2001), *Geology of Belorussia* (in Russian), 815 pp., Science and Technology, Minsk.

Nikolaev, V. G. (1999), Riphean tectonic prehistory of the Moscow Syneclise, *Geotectonics* (in Russian), *33*(6), 59.

Puura, V. A. (1974), K-Ar age of the crystalline basement rocks in the north of the Baltic region, *Proc. Estonian Academy, Ser. Chem. and Geol., 23*(1), 40.

Raukas, A., and H Hyuvarinen, (Eds.), (1992), *Gulf of Finland Geology,* 492 pp., Valgus, Tallin.

Romanov, V. A., and M. V. Isherskaya (2001), *Riphean Rocks in the Platform Regions of Bashkortostan: Stratigraphy, Tectonics, and Oil and Gas Prospects,* 125 pp., Ufa Press, Ufa.

Ryka, W. (1973), Formacja Jotnicka, Skaly Platformy Prekambryjskiej w Polsce, *Kwartalnik Geologiczny, 12*(1/2), 113.

Semikhatov, M. A. (1986), *Stratigraphy and Geochronology of the Proterozoic,* 302 pp., Nedra, Moscow.

Shcherbak, N. P., K. E. Esipchuk, and B. Z. Berzenin (1985), Precambrian stratigraphy of the Ukrainian Shield, in *Precambrian Stratigraphy of the Ukrain,* p. 10, Naukova Dumka, Kiev.

Stirpeika, A. D. (1987), Hoglandian and Early Riphean volcanogenic sedimentary rocks in the Baltic region, in *The Tectonics, Facies, and Rock Formations in the West of the East European Platform,* p. 39, Science and Technology, Minsk.

Velikoslavinskii, D. A., A. P. Birkis, and O. A. Bogatikov (1978), *The Anorthosite-Rapakivi Granite Suit of the East European Platform* (in Russian), 146 pp., Nedra, Leningrad.

Verkhoglyad, V. M. (1995), The periods of the magmatic activity in the Korosten Pluton, *Geochemistry, 21,* 34.

Yanshin, A. L., R. G. Garetskii, and A. E. Shlezinger (1974), The contribution of the geoscientists of the Russian Academy to the elaboration of the platform doctrine and some modern aspects of the latter, *Geotectonics* (in Russian), *8*(3), 6.

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