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Riphean sedimentary sequences of the eastern and northeastern margins of the Eastern European craton

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Abstract. The Riphean history of depositional basins in the study region can be divided into Early-Middle Riphean and Late Riphean phases. Throughout the Riphean, clastic material was supplied chiefly from eastern regions of the Russian craton. Deposition occurred mainly in semi-arid environments, humid and near-glacial epochs being considerably shorter. Riphean carbonate and siliciclastic sedimentary deposits are dominated by those of shallow-water and nearshore basin environments. In the Early and Middle Riphean, the principal type of depositional basins in the study region was relatively small epicratonic seas. The peculiarities of architecture and spatial distribution of the Late Riphean sedimentary deposits suggest that in the middle or end of this timespan, there appeared a major cratonic-margin basin that covered the entire eastern and northeastern margins of the Eastern European craton.

Significant controversy exists regarding the formative conditions of Riphean sedimentary sequences sitting at the eastern and northeastern, to use a modern reference frame, margins of the Eastern European craton. Thus, *Ivanov et al.* [1986] negate the existence of an ocean in the Riphean and Vendian east of the Urals, and, hence, the presence of sedimentary assemblages of passive margins in its western sector. In the Riphean, this sector was a continental margin overlapped by thick sedimentary and volcanosedimentary assemblages. According to *Puchkov* [2000, p. 29], accumulation of schist/quartzite and carbonate piles there "was merely interrupted by rifting pulses ... ." *Surkov et al.* [1993] argue that, in the initial Riphean in central Laurasia, a long-lived mantle plume was formed, responsible for a crustal arch and a fan-shaped system of rift-related intracontinental sedimentary basins. In the opinion of these workers, Riphean assemblages of the western sector of the Urals are similar in origin to sedimentary sequences of passive margins of young oceans. Notions like this are also to be found in [*Mossakovsky et al.,* 1996; *Samygin,* 2000; etc.].

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Within the area in point, Early Riphean sedimentary sequences have only been reported from what is now the Bashkir meganticlinorium and the Volga–Uralian region. They fill in a large cratonic basin with fragmented basement and are represented by coarse terrestrial clastics and nearshore marine terrigenous deposits, as well as by moderately deep-water sediments originating from environments with restricted circulation. The lack of Lower Riphean sedimentary assemblages on the western slope of the Middle and North Urals and in the Timan–Pechora region [*Stratigraphic...,* 1993] suggests that the Early Riphean depositional basin did not extend appreciably beyond the limits of the present-day Volga–Uralian region and the western slope of the South Urals.

Deposition of the Middle Riphean sediments was predated by a rearrangement of the structural grain. In the initial Middle Riphean, on the east of the Bashkir meganticlinorium, there apparently formed a relatively narrow rift-related (?) depression, where the volcanosedimentary pile of the Mashaksky Formation, as thick as 2700–3300 m, was deposited almost instantaneously, in terms of geologic time scale. Subsequently, this feature turned into a considerably wider sag that enclosed adjoining portions of the Eastern European craton as well. The Mashaksky Formation bears conglomerate lenses and beds as thick as 30 or even 100 m. The conglomerates were deposited in nearshore zones of a marine (?) basin surrounded by mountainous land. The

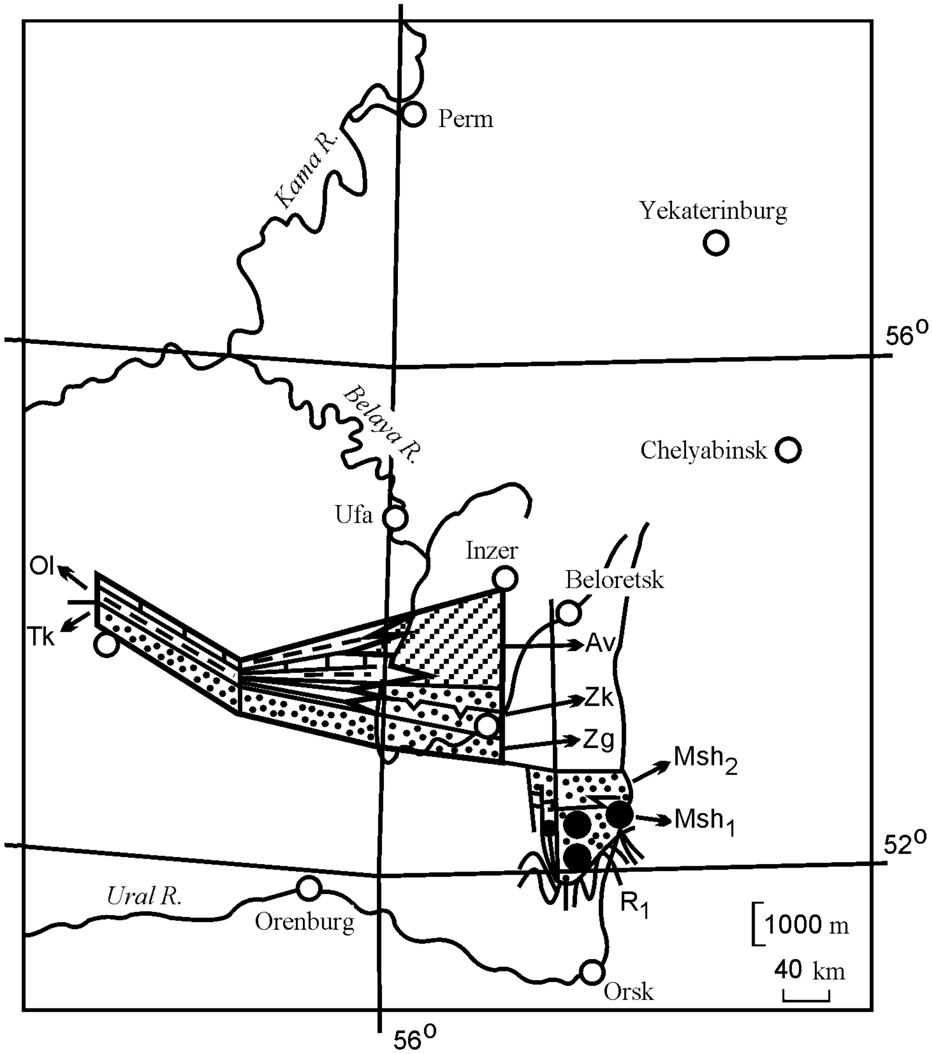

Figure 1. Spatial distribution of major sedimentary assemblages of distinctive compositions and origins at the eastern margin of the Eastern European craton and in the western megazone of the Urals (Middle Riphean, as per the notions of the mid-1980s to 1990s, after [*Getsen et al.,* 1987]).
1 – volcanic–terrigenous assemblages of nearshore terrestrial and nearshore marine origins; 2 – sand–silt deposits of nearshore and shallow marine origins; 3 – sand-dominated nearshore terrestrial deposits; 4 – clay–silt deposits of distal portions of the basin; 5 – carbonate–terrigenous shallow marine sequences; 6 – same, of nearshore marine origin. Lettering denotes: R_1 – Lower Riphean; Msh_1 – lower unit of the Mashaksky Formation; Msh_2 – upper unit of the Mashaksky Formation; Zg – Zigalginsky Formation; Zk – Zigazino-Komarovsky Formation; Av – Avzyansky Formation; Tk – Tukaevsky Formation; Ol – Olkhovsky Formation; R_2Cht – Chetlassky Group; R_2(?)Tar – Tarkhanovsky Group.

bulk of the Mashaksky psephitic clastics, supplied to the basin from the west and northwest, were derived from eroding sedimentary and metasedimentary rocks.

The Middle Riphean sequences in the Volga–Uralian region and on the western slope of the South Urals were dominated by terrigenous nearshore and shallow marine deposits, and it was not before ca. 1220 Ma that the depositional area became the site of accumulation of shallow water carbonate and carbonate–terrigenous sequences (Avzyansky Formation). The character of thickness variations of the Middle Riphean lithostratigraphic units that make up the vertical stratigraphic succession across the area from Perm to Orenburg and from Samara to Zlatoust differs perceptibly from that intrinsic in the Burzyan. Here, since the Early Riphean, depocenters have tended to cluster within the Volga–Uralian region, and the greatest thicknesses, to migrate toward the present-day Urals (Mashaksky time) [*Maslov,* 2000].

The issue of whether or not Middle Riphean sedimentary sequences are present within the western slope of the Middle and North Urals, on the Polyudov Ridge, and in the Timan–Pechora region, remains as yet open to discussion [*Olovyanishnikov,* 1998], with the ensuing mutually exclusive viewpoints regarding the development of deposition in the study area during the timespan just mentioned (Figures 1, 2) [*Getsen et al.,* 1987; *Olovyanishnikov,* 1998; and others].

At the Middle/Late Riphean transition, the depositional area that had existed within the present-day Bashkir meganticlinorium suffered, once again, emergence and erosion of the deposits accumulated previously. This is supported by the appreciable thickness scatter of the so-called Tyulmensky Subformation, crowning the Avzyansky Formation, by the cardinal change in the directions of aluminosilicate clastics transport and in the general style of development of the depositional basin, as well as by the analysis of depositional rates of terrigenous and carbonate assemblages of different origins within the Yurmatinsky Group [*Maslov et al.,* 2001].

In the Late Riphean (Karatavian), a major cratonic-margin sag took shape, which stretched at least from the EW reach of the Belaya River via the western slope of the Middle Urals through the Polyudov Ridge into the Timan–Pechora region and, probably, as far as the northern margin of the Kola Peninsula. At the beginning of the Karatavian, the region of the present-day Bashkir meganticlinorium became a repository for tremendous amounts of arkosic quartz–feldspthic clastics, supplied from the west and northwest, to be accumulated in a vigorously sagging steady-state or overfilled basin in fluvial, deltaic–fluvial, and nearshore environments. In the second half of Zilmerdak time (ca. 950–980 Ma), shallow marine terrigenous strata were formed, to be succeeded, in Katavsky time (ca. 830–850 Ma), by redbed shallow marine clayey carbonate deposits. The middle and upper Karatavian strata are dominated by shallow water aluminosilicate clastics and carbonate sedimentary sequences.

In the Middle and Northern Urals, the Upper Riphean is represented by deposits of the Sinegorsky, Klyktansky, and Kyrminsky Formations, and on the Polyudov Ridge, by the Rassolnensky, Deminsky, and Nizvensky Formations [*Stratigraphic...,* 1993]. These Formations, in all likelihood, were deposited at conditions similar to those reconstructed for their counterparts in the standard section.

In the Timan–Pechora region, to judge from [*Olovyanishnikov,* 1998], most Formations and Groups that were formerly ascribed to the Middle to Upper Riphean, belong to the Upper Riphean and Lower Vendian. This viewpoint, however, is not commonly accepted, and, hence, several opinions exist as for the type and character of the Late Riphean depositional basin that stretched from the South Urals to Timan and Kanin Peninsula, eventually to merge with the basin that existed at the northern margin of the Kola Peninsula (compare, e.g., [*Getsen et al.,* 1987] and [*Olovyanishnikov,* 1998]) (Figures 3, 4).

Let us attempt a summary of the most general parameters of Riphean sedimentary sequences, such as the dominant lithologic composition, characteristic primary sedimentary structures, the thickness of deposits and the character of its variations, the presence and character of breaks, cyclicity, characteristic facies assemblage, peculiarities of their vertical and lateral "organization" in the sections of major sedimentary Groups, depositional environments, etc.

In Riphean sections, sandstones are dominated by mineralogically moderately mature to mature arkosic, subarkosic,

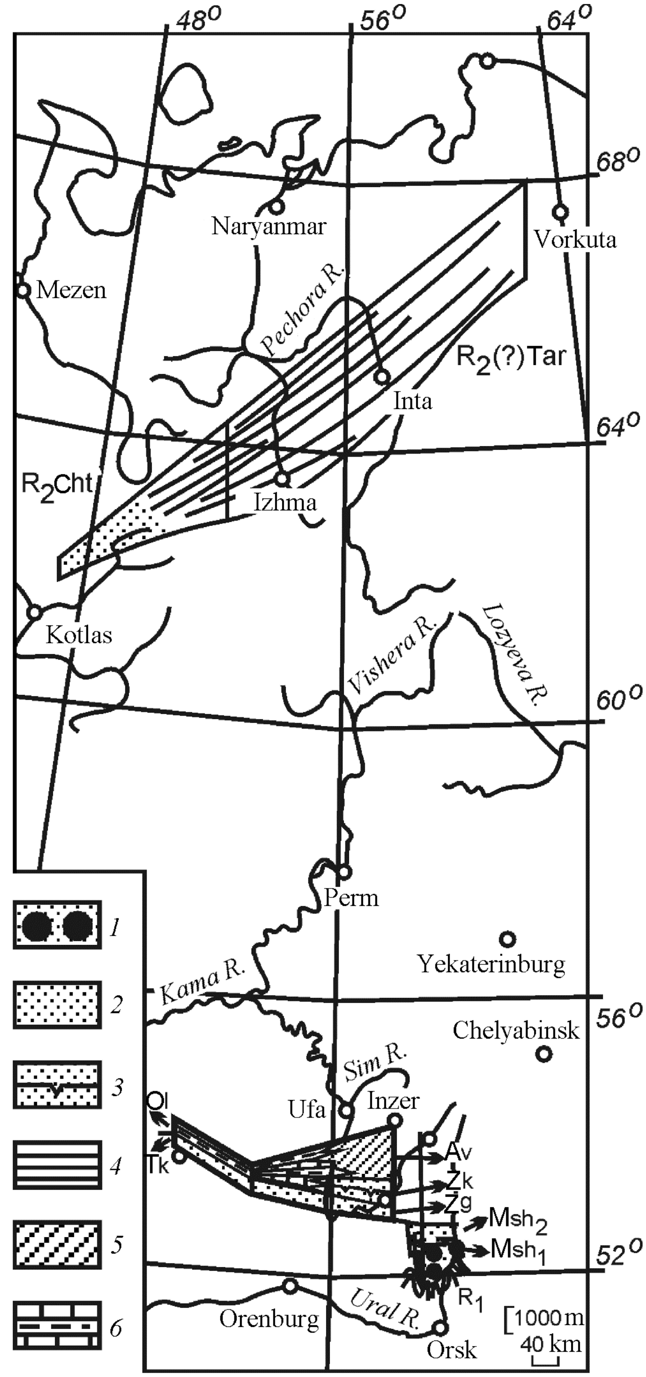

Figure 2. Spatial distribution of major sedimentary assemblages of distinctive compositions and origins at the eastern margin of the Eastern European craton and in the western megazone of the Urals (Middle Riphean, as per the notions of the late 1990s, after [*Olovyanishnikov,* 1998]). Symbols, as in Figure 1.

quartz–feldspthic, and quartz varieties, suggesting that erosion involved crystalline basement assemblages and metasedimentary and sedimentary rocks and that formation of the psammitic framework was affected by clastics maturation processes. Partly, the Riphean sedimentary assemblages (in the northern Kola Peninsula, Timan–Pechora region, etc.), along with arkosic and quartz–feldspthic sandstones, are also characterized by psammitic graywacke varieties, found as constituents in thick turbidite sequences.

Primary depositional structures of the rocks are extremely diversified, emphasizing the existence of two "mega-assemblages" that can be termed, for convenience, "shelf" and "slope." The former is dominated by deposits of multichannel fluvial, deltaic–fluvial, and nearshore terrestrial plains and of littoral, intertidal, and shallow marine zones of basins (above the storm wave base). These exhibit a broad variety of cross, multidirectional cross, scallop, lenticular, swaley cross, undulatory cross, low angle wavy, flaser, pinch-out, trough-like, horizontal and near-horizontal, convolute, and graded laminations, as well as ripples, symmetrical ripples, desiccation cracks, micro–scour marks, scour grooves, pseudomorphs after halite and sulfate minerals, various sole marks, load casts, flutes, raindrop casts, intraclastic shale breccia at the base of sand beds, incised valleys, sediment shrinkage structures, etc. In carbonate units, one finds stromatolite buildups of various types, intercalations and lenses of syndepositional intraclastic breccias, syneresis cracks, silica pseudomorphs after halite, as well as various lamination types, etc. The other mega-assemblage is dominated by gravitational deposits (classical turbidites, debris and fluidized flow deposits, collapse and slump deposits and such like, formed in submarine slope environments), with the entire spectrum of their intrinsic structures.

In these sedimentary sequences, several types of thickness variation patterns are discernible. One type covers a thickness distribution pattern, called "centripetal" for convenience, where thickness increases gradually from proximal to distal portions of the basins. This is most clearly exemplified by Lower Riphean sequences of the Burzyan and Kyrpinsky Groups in the Volga–Uralian region and Bashkir meganticlinorium. In parallel, reconstructed is a transition from nearshore shallow water and "super–shallow water" sedimentary assemblages to deposits of open and moderately deep-water zones of basins. In northern areas of Norway and Kola Peninsula, in the Timan–Pechora region, and to some extent, possibly, in Upper Riphean sections of the Middle and North Urals, thickness distribution pattern is different. Based on the lithotype spectrum, composition of sandstone assemblages, coloring, and facies aspect of deposits, one discerns here a nearshore shelf and a distal slope region. The sedimentary assemblages of the latter exhibit much greater thicknesses than the former.

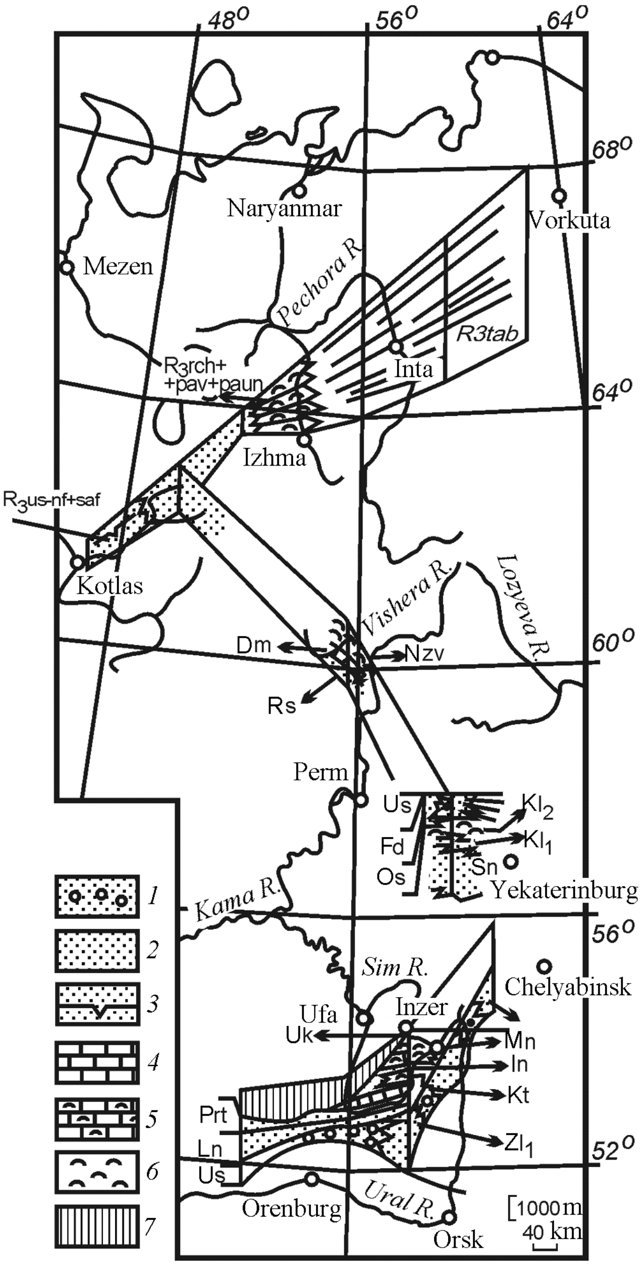

Figure 3. Lateral and vertical distributions of major sedimentary assemblages of distinctive compositions and origins at the eastern margin of the Eastern European craton and in the western megazone of the Urals (Late Riphean, as per the notions of the mid-1980s to 1990s, after [*Getsen et al.,* 1987]).

1 – terrigenous assemblage of fluvial and deltaic–fluvial origins; 2 – sand–silt nearshore and shallow marine deposits; 3 – sand-dominated nearshore terrestrial deposits; 4 – carbonate deposits of shallow marine origin; 5 – same, with subtidal stromatolite buildups; 6 – carbostrome formation, after B. M. Keller; 7 – erosion. Lettering denotes: Zl_1 – Biryansky Subformation of the Zilmerdak Formation; Kt – Katavsky Formation; In – Inzer Formation; Mn – Minyarsky Formation; Uk – Uksky Formation; Us – Usinsky Formation; Ln – Leonidovsky Formation; Prt – Priyutovsky Formation; Kl_1 – Lower Subformation of the Klyktansky Formation; Kl_2 – Upper Subformation of the Klyktansky Formation; Os – Oslyansky Formation; Fd – Fedotovsky Formation; Usv – Usvinsky Formation; Rs – Rassolnensky Formation; Dm – Deminsky Formation; Nzv – Nizvensky Formation; R_3Ust-Nf+Saf – Ust-Nyaftinsky and Safonovsky Groups; R_3Rch+Pav+Paun – Rochugsky, Pavyugsky, and Paunsky Formations; R_3Tab – Tabuevsky Group.

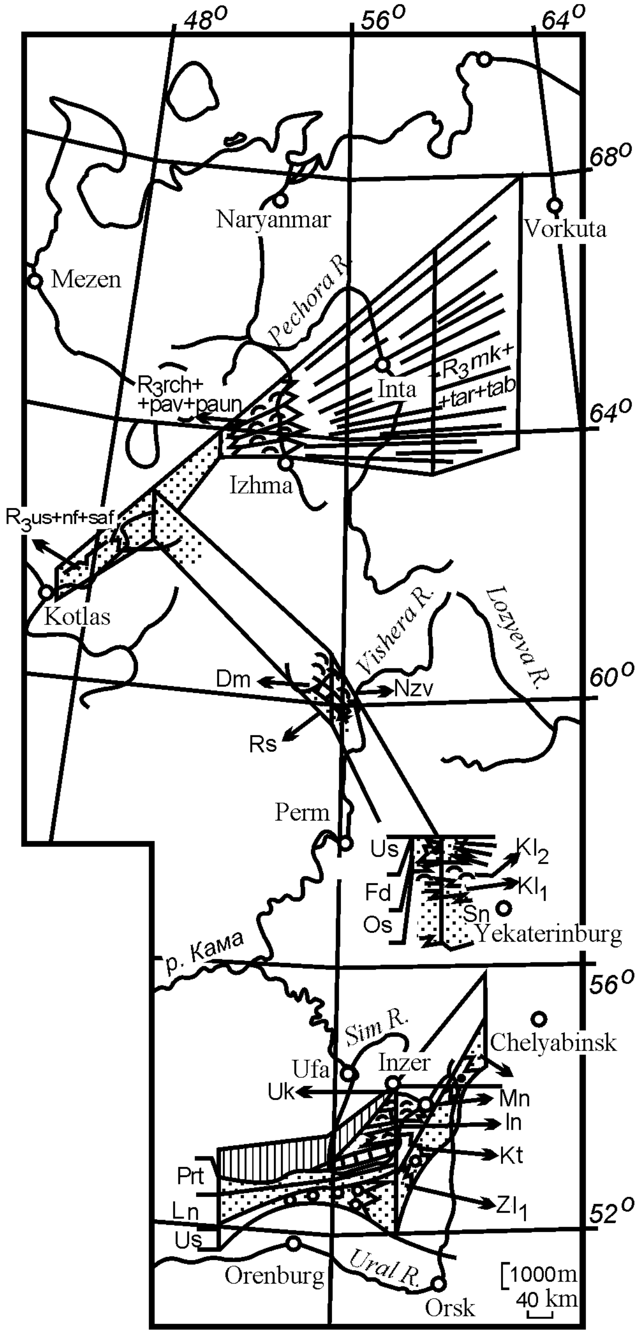

Figure 4. Lateral and vertical distributions of major sedimentary assemblages of distinctive compositions and origins at the eastern margin of the Eastern European craton and in the western megazone of the Urals (Late Riphean, as per the notions of the late 1990s, after [*Olovyanishnikov,* 1998]). Symbols, as in Figure 3. R_3Mk+Tar+Tab – Mikulinsky, Tarkhanovsky, and Tabuevsky Groups. Other symbols, as in Figure 3.

Large-scale cyclicity within Riphean sedimentary groups is most spectacular in the Karatau Group of the Bashkir meganticlinorium. In some respect, this cyclicity resembles the macrocyclicity of the post-Rapitan portion of the Windermere Supergroup. On Mackenzie Mts., northwestern Canada, the Windermere Grand Cycles are a typical drift-related assemblage, deposited, according to the american and canadian workers, on a passive continental margin owing to eustatic sealevel changes. The thick coarse arkosic sandstone sequences, occurring in the basal portion of the Karatau Group (Biryansky Subformation of the Zilmerdak Formation), also, seemingly, corroborate this assumption. The facies aspects of the Windermere grits and the arkosic Biryansky Subformation of the Zilmerdak Formation, however, are dramatically dissimilar. The lower Windermere strata are represented by thick sequences of poorly sorted, mostly non-bedded sandstone–gravel deposits, formed at deep-water and moderately deep-water conditions with a vigorous tectonic impact on depositional processes. By contrast, Biryansky level sections are dominated by terrestrial and nearshore terrestrial deposits.

Riphean sedimentary sequences in the study region are represented by a broad variety of facies assemblages that are, however, dominated by "super–shallow water" and shallow water shelf deposits; a perceptibly smaller or, in some areas, roughly equal part is played by turbidites and related types of deposits formed by massive gravitational transport of clastic material, as well as terrestrial assemblages resulting from the activity of shallow water multichannel fluvial and deltaic-fluvial systems. The architecture of the facies assemblages and of larger units composed by them—sedimentary assemblages—within the Burzyan, Yurmatinsky, and Karatau Groups suggests that each of these has "a face of its own." In the Early, Middle, and Late Riphean, the development of depositional basins, once existing in what is now the Volga–Uralian region and the western slope of the South Urals, took place in paleotectonic, paleogeographic, and paleoclimatic environments that were specific to each of these major phases, and that were responsible for the formation of depositional sequences with distinctive architectures of their sedimentary and facies assemblages.

The compositions of distributive provinces are rather closely similar for nearly all the Riphean sedimentary sequences in the study region. Of greatest interest is the fact that Riphean sections in the Volga–Uralian region, Bashkir meganticlinorium, and the northern Kola Peninsula offer evidence for reconstructing the past existence, in erosion regions, of pre-Riphean metasedimentary deposits that were, most likely, cratonic cover to crustal masses that had become stable by the middle or end of the Early Proterozoic [*Khain and Bozhko,* 1988].

We thus can discern several types of major sedimentary sequences that existed in the Riphean on the east and northeast of the Eastern European craton and that, to one or another extent, characterize the preexisting depositional paleobasins (or, more exactly, their fragments). The basis for identifying these types is provided by the previous analysis of Riphean sedimentary sequences of the Northern Hemisphere [*Maslov,* 1998].

Type one covers Upper Riphean deposits of the Karatau

Group. Its lower strata are dominated by terrestrial and nearshore terrestrial arkosic and subarkosic rocks with subordinate nearshore and shallow marine deposits, whereas its middle and upper strata are made up of cyclically alternating terrigenous carbonate rocks of shallow water and, occasionally, moderately deep-water origins. Carbonate and terrigenous sediments alternating within the Group may record sealevel variations (including eustatic ones) and/or changes in clastic input to shallow water zones of the basin.

Type two includes Lower Riphean sequences of the Burzyan and Kyrpinsky Groups on the western slope of the South Urals and in the Volga–Uralian region. Based on paleogeographic reconstructions and seismic profiles, these deposits fill in a relatively large epicratonic basin, roughly oval in shape. Within the currently known distribution area of Lower Riphean sedimentary deposits, their thickness has been reported to increase gradually from proximal to distal zones of the paleobasin, in strict compliance with the term "centripetal distribution," with near-terrestrial and nearshore marine facies giving way to distal deposits of outer shelf and, occasionally, of deeper zones. Depositional sequences of this type either contain a very limited proportion of volcanic assemblages or none at all. Middle Riphean sequences of the Volga–Uralian region and the western slope of the South Urals (Serafimovsky and Yurmatinsky Groups) exhibit features that are intermediate between the first and second types; this is especially readily apparent from the thickness variation pattern of deposits of each of the four levels [*Maslov,* 2000].

Type three of sedimentary sequences is encountered in the northern Kola Peninsula, in Finnmarken, and in the Timan–Pechora region. It is characterized by (1) a lateral assemblage of shallow-water shelf and deep-water (slope) deposits, represented by arkosic and quartz–feldspthic sandstone, siltstones, and mudstones, and by psammitic graywacke, respectively, and (2) sediment thickness increasing considerably in a distal direction.

Overall, the Riphean history of depositional basins in the study region can be divided into two phases of unequal duration: Early–Middle Riphean and Late Riphean. Throughout the Riphean, clastic material was supplied chiefly from eastern regions of the Russian craton. Deposition occurred mainly in semi-arid environments, humid and near-glacial epochs being considerably shorter. Riphean carbonate and siliciclastic sedimentary deposits are dominated by those of shallow-water and nearshore basin environments. In the Early and Middle Riphean, the principal type of depositional basins in the study region was relatively small epicratonic seas. The peculiarities of architecture and spatial distribution of Late Riphean sedimentary deposits suggest that in the middle or end of this timespan, there appeared a major cratonic-margin basin that covered the entire eastern and northeastern margins of the Eastern European craton. The architecture of its sedimentary fill in a number of regions (Timan–Pechora region, northern Kola Peninsula, possibly the Middle Urals) displays certain features inherent in sedimentary sequences of passive margins. Its proximal (shelf) portion evidently corresponded to what is now the Bashkir meganticlinorium and the Volga–Uralian region, while its distal (slope and rise) portion is reconstructible within the Timan–Pechora region. Under this setup, principal structural units of this basin were perceptibly discordant to the structural grain of the Early Paleozoic Uralian paleocean.

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