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Pleistocene Sediments in the Shapkina River Valley (Bol'shaya Zemlya Tundra)

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Abstract—Facies–genetic and stratigraphic subdivision of the Quaternary sequence in the Shapkina River valley has been accomplished. The riverbank shows outcrops of three glacial complexes with different mineralogical–petrographic compositions and structural characteristics, which can be correlated and stratificated. Datings of intermoraine horizons (alluvial, marine, lacustrine, and lacustrine–boggy sediments) have been based on the palynological and paleomicrotheriological data. The middle Neopleistocene section can be divided into two till horizons corresponding to two autonomous glaciations (Pechora and Vychegda). They are separated by a member of subaqueous Rodionov sediments. The Pechora till formed in the course of motions of glaciers from the northeast. Glacial horizons are mainly composed of the Vychegda till delivered from the Northwest terrigenous provenance. Lithology of the upper Neopleistocene Polyarnyi till testifies to its formation in the upper course of the river from material delivered from the Northeast terrigenous–mineralogical provenance in the upper course of the river and from Fennoscandian glaciation center in the lower course of the river. The paper presents the first lithological investigation and substantiation of genesis of various facies of Neopleistocene intermoraine marine sediments (sediments of the beach and fore-beach zones and shallow-water shelf).

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Issues of the genesis of the major part of the Quaternary section, which is composed of boulder-containing clayey rocks (diamictons), Neopleistocene stratigraphy, and paleogeographic reconstructions of the European Northeast is being discussed over several years. In particular, issues of the rank of the second (Moscovian) Middle Neopleistocene Glaciation (Vychegda Glaciation, according to the regional scheme) and the stratigraphic affiliation of the Shklov (Rodionov) Interglacial remain debatable (*Chetvertichnye oledeneniya...*, 1987; Duryagina and Konovalenko, 1993; Maudina et al., 1985; Velichko, 1981). Issue of the late Pleistocene paleogeography is also ambiguous. The number of Valdaian glaciers, timing of their advance, location of their provenances, and boundaries of the last sheet glaciation in the region are also controversial issues (Astakhov, 1999; Astakhov et al., 1999a, 1999b; Grosswald, 1994, 1998; Mangerud et al., 1999; Spasskaya et al., 1993; Velichko et al., 2000).

At present, several models of the last glaciation have been presented for the Russian Arctic. According to the most popular model proposed by Velichko et al. (Spasskaya et al., 1993; Velichko, 1987; Velichko and Faustova, 1989; Velichko et al., 1997; 2000), the local continental glaciation included separate glaciers with centers located on archipelagoes of the Barents–Kara shelf and in the Polar Urals. The Kara Sea was an ice-free land. According to another model (Grosswald, 1983, 1988, 1994, 1998) based on aerial geological survey data (Arslanov et al., 1975, 1987; Lavrov, 1974, 1977a, 1977b, 1977c), glaciation in the Arctic represented a solid marine ice sheet that covered a significant part of the European Northeast with center located in the Kara Sea. The Kara ice sheet appeared earlier and disappeared later than other ice sheets in Eurasia. Thus, the ice sheet continued to exist up to 8.5 ka B.P., i.e., the Marchid Stage.

According to the third model based on results of the joint Russian-Norwegian PECHORA project (Astakhov et al., 1999a, 1999b; Mangerud et al., 1999), both Valdaian ice sheets represented continental varieties during their maximum phase and their centers were located on drained shelves of the Kara and Barents seas; i.e., the ice mass was mainly transported from the Arctic shelf, which incorporated the highest ice domes. The maximum phase of the last sheet glaciation occurred in the early Valdaian time (100–60 ka B.P.) rather than the late Valdaian interval (25–10 ka B.P.). All other researchers strongly exaggerate the dimension of the last sheet glaciation in the region.

We believe that all models mentioned above are ambiguous. Despite the increasing interest of the international scientific community, this issue is far from its solution. We assume that any model, including the model of the last glaciation, should be substantiated with the consideration and analysis of all available factual materials pertaining to the Quaternary geology of the region. The model should also take into account the

Table 1. Comparison of regional and interregional stratigraphic charts of Quaternary sediments in the East European Platform (*Reshenie ...*, 1986)

Series	Stage	Regional stratigraphic scheme of the Timan–Pechora–Vychegda region		Interregional stratigraphic scheme of Quaternary sediments in the East European Platform	
		Suprahorizon	Horizon	Suprahorizon	Horizon
Pleistocene	Holocene Q_{IV}		Holocene		Holocene
	Upper Q_{III}	Nenets	Polyarnyi Byzovaya Laya	Valdai	Ostashkovo glacial Leningrad interglacial Podporozh'e glacial
			Sula		Mikulino interglacial
	Middle Q_{II}	Timan–Ural	Vychegda Rodionov Pechora	Middle Russian	Moscovian (Sozh) glacial Shklov interglacial Dnieper glacial
			Chirva		Likhvin interglacial
	Lower Q_I	Komi–Perm	Pomusov Vishera Bereza		Oka (Bereza) glacial Belovezh (Muchkap) interglacial Don (Dzuki) glacial
			Tum Kam	Vilnius	Il'in interglacial Pokrov glacial Mikhailov interglacial

available palynological, paleontological, and lithological data testifying to the late Valdaian age of the relief-forming moraine in the northernmost area.

The regional stratigraphic scheme of Quaternary sediments in the Timan–Pechora–Vychegda region (Table 1) was approved by the Commission for the Quaternary System of the Interdepartmental Stratigraphic Committee as early as 1984 (*Reshenie ...*, 1986). However, the issues mentioned above remain debatable to date.

In the Shapkina River valley, the middle Neopleistocene section is divided into two till horizons—Pechora (Dnieper) and Vychegda (Moscovian)—that are separated by an subaqueous sedimentary member assigned to the Rodionov (Skhlov) Horizon based on the palynological dating method (Guslitser et al., 1985). They are sandwiched between two glacial horizons with lithological signatures of the Pechora and Vychegda tills (Andreicheva, 2002a), suggesting two episodes of glaciation of the region in the middle Pleistocene epoch. Discrepancies in the lithology of tills in these horizons indicate their formation under conditions of drastic changes in glaciation centers and the autonomous character of continental glaciers, which produced the moraines.

The Rodionov age of marine sediments (beach, bar, intertidal, and other facies) is based on their conformable occurrence between the Pechora and Vychegda glacial horizons. The Rodionov age of the member composed of alluvial, lacustrine, and lacustrine–boggy sediments has been determined nearly everywhere by the palynological method. In some sections, the dating is based on paleomicrotheriofauna in the underlying periglacial alluvium.

The Sula (Mikulino) interglacial horizon is widespread. The stratigraphic affiliation of its marine, lacustrine, and alluvial sediments is rather arbitrarily based on their conformable occurrence on the Vychegda till.

The fragmentarily developed Byzovaya (Leningrad) Horizon is composed of lacustrine sediments. Identification of this unit in the region is based on its occurrence on the Laya (Podporozh'e) periglacial alluvium with the lemming fauna.

METHODS

We carried out the layer-by-layer description of each section during the fieldwork. Neopleistocene sediment samples were taken for the lithological, palynological, and microfaunal analyses. Special attention was devoted to sedimentological indicators: attitudes of rocks; contact between genetically different sediment layers; structure of deformed intermoraine sediments and tills; and presence, distribution type, and roundedness of clastic material. When studying structural features of sediments, we took into consideration not only the well-known works (Botvinkina, 1962, 1965), but also recent concepts of structural analysis (Boggs, 1995; *Facies Models...*, 1992; Gradzinsky et al., 1980; Leeder, 1982; Reineck and Singh, 1980; *Sedimentation Environment...*, 1986; Selley, 1976, 1978). Results of the palynological analysis and data on the paleomicrotheriology and correlation of river terraces were used for the stratification of sediments. We also scrutinized the lithology of tills. Lithological data are suffi-

ciently efficient and reliable for the correlation and relative dating of tills. Petrography of a large volume of clastic material (0.25 m^3) from tills was studied to establish the provenances (Lavrov, 1976). Fraction 1–10 cm appeared to be most representative in terms of both volume and diversity of petrographic varieties of sediments that reflect compositions of the distal, transit, and proximal provenances. The following petrogenetic groups were identified for the petrographic correlation of the major till sequences (Gaigalas, 1979):

(1) Paleozoic dark gray and black carbonate rocks;

(2) Paleozoic light gray and white carbonate rocks;

(3) local (proximal) Mesozoic sandstones (Jurassic light gray sandstones with dark plant detritus; Cretaceous quartzose and glauconite sandstones; siltstones; clayey–carbonate, pyrite, and siderite nodules; fossil wood and coal fragments; belemnite rostra; and ammonite shells);

(4) Permian and Triassic terrigenous rocks;

(5) igneous and metamorphic rocks; and

(6) quartzite sandstones and quartzites.

Till horizons of different ages were outlined on the basis of proportions of these rock groups.

Numerous measurements of the orientation of elongate fragments were carried out to determine the direction of terrigenous material transport. Orientation of no less than 50 boulders was measured at each observation site and the results were presented as rose diagrams.

During the laboratory work, we applied all routine procedures used for elucidating the lithological composition of the entire grain size distribution of sediments. The grain size distribution in sediments of various genetic types was studied to decipher their structural pattern. Interpretation of the results was based on bar charts, cumulative plots, and ternary and pair diagrams. Genetic diagrams were also plotted. Average diameter (d_{av}) and coefficient of sorting (S_c) were calculated for all samples. We expressed the sorting of sediments by normalized entropy, which only depends on the weight of fractions and does not depend on the grain size (Belkin and Ryazanov, 1972). The S_c value varies from 0 in the fine-grained sediments sorted worst of all to 1 in the monofraction sediments.

The mineral composition of the fine-grained sediments was analyzed in the 0.25–0.1 mm fraction, which is sufficiently representative in weight and accessible for study. Moreover, this fraction serves as the proxy of proximal, transit, and distal provenances. Thin sections were investigated to decipher the mineral composition, microstructures, and microtextures of rocks. The diffractometric analysis of the clayey fraction was carried out to elucidate the inherited composition of the fine-dispersed fraction of tills from rocks of the glacial substrate.

The palynological and paleomicrotheriological analyses were carried out by D.A. Duryagina and V.A. Kochev, respectively, in accordance with routine procedures. The results were used to determine the relative age of intermoraine sediments and to reconstruct the paleogeographic sedimentation environment.

RESULTS AND DISCUSSION

We scrutinized 13 outcrops located 92–286 km from the mouth of the Shapkina River basin (Fig. 1). Locations of the sections studied are shown in the profile (Fig. 2). They have different geological structures in the upper and lower courses of the Shapkina River. Sections in the upper course contain three glacial complexes of tills and genetically related sediments. They alternate with genetically different interglacial (alluvial, lacustrine, marine, solifluction, and lacustrine–boggy) sediments. Below the mouth of the Vonda River, the sections are composed of lacustrine and lacustrine–boggy clays and silts with peat layers at the base (Fig. 2). The age of these sediments is differently interpreted by researchers (Berdovskaya and Loseva, 1975; Lavrov et al., 1986; Loseva, 1978; Loseva and Arslanov, 1975).

We can identify 14 lithostratigraphic members in the summary section of stratigraphic successions exposed on the riverbank (Fig. 3). They were traced at succesive outcrops along the riverbank. Based on the complex study of tills and in accordance with the scheme of lithological correlation of moraines (Andreicheva, 1992), we can outline three till horizons of different ages in sections exposed the Pechora basin north of 67° N. The Vychegda and Pechora horizons formed in the middle Neopleistocene, whereas the Polyarnyi till has the late Valdaian age.

Member 1 (Pechora Till, $Q_{II}^2 pč$)

Member 1 is only identified at outcrop 6 on the right bank of the Shapkina River facing the mouth of the Vangureivis Creek and is buried elsewhere beneath the river water. The Pechora till (apparent thickness >6 m) is composed of dark gray coarse-platy loam with abundant gravel, pebble, and boulder. Elongate fragments have the southwestern orientation. The irregular (nearly horizontal) upper contact of the Pechora moraine horizon is emphasized by the presence of boulder pavement with an abundance of secondary iron and manganese minerals. The lower contact is unexposed.

Fragments from the Pechora till are mainly composed of carbonate rocks (38.5%), dark-colored limestones and dolomites (29.7%), and rare pink marbleized crinoid–bryozoan limestones from Novaya Zemlya (Table 2).

Fragments of local Jurassic and Lower Cretaceous sediments make up 36.2% of the section. Pyrite concretions are subordinate. Fragments of distal rocks are as follows: Permian and Triassic terrigenous rocks 19.8%,

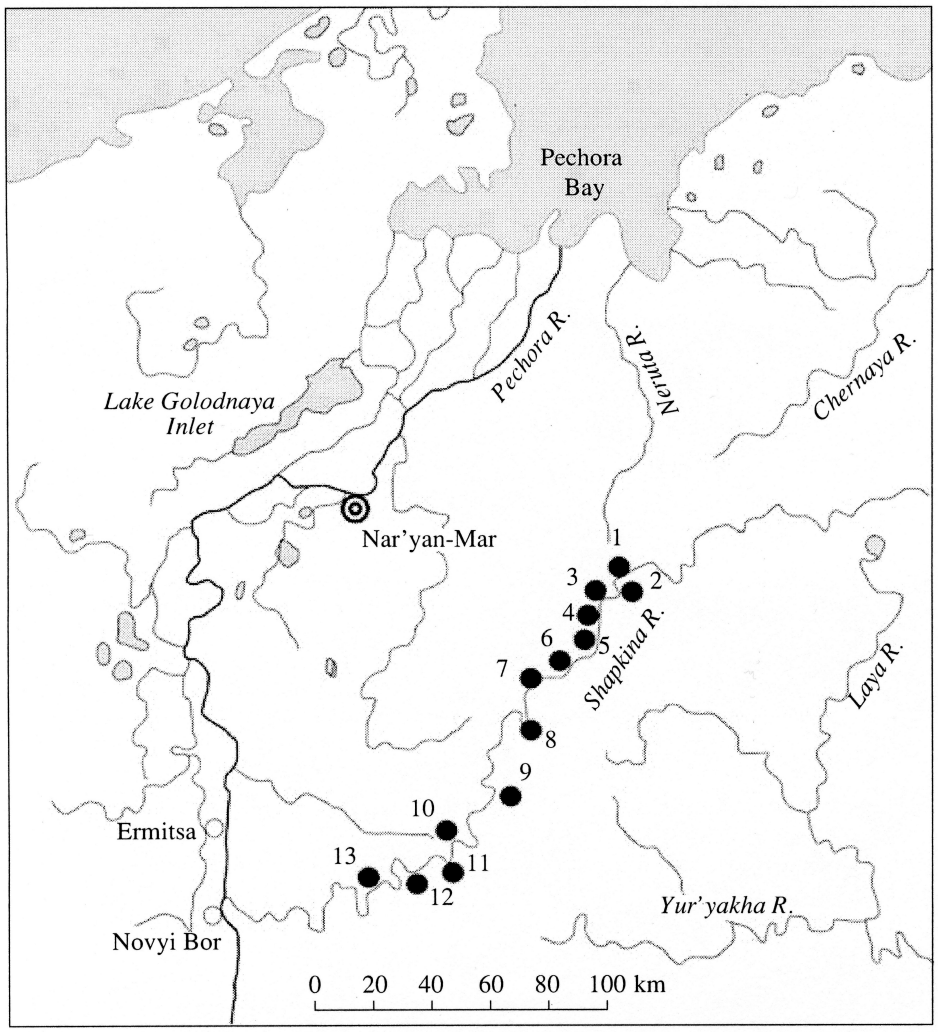


Fig. 1. Schematic position of the studied outcrops (1–13).

quartzite sandstones and quartzites 3.3%, and schists 1.1%. The content of igneous and metamorphic rocks is substantially lower (2.2%) than in other till horizons.

The trend of grain size reduction found in the major types of till from northeastern Europe (Andreicheva, 2002a) is absent in the stratigraphic succession of the Shapkina River valley basin. Here, in contrast, the Pechora till appears to be most enriched in the clayey component (d_{av} = 0.012 mm). This conclusion is based on the study of grain size composition of the Pechora till in only one section. The percentage ratio of gravelly-sandy, silty, and clayey fractions of the fine-grained material in the Pechora till is 20 : 35 : 45. As compared to other areas of the Timan–Pechora–Vychegda region, the Pechora till in the Shapkina River valley is slightly better sorted (S_c = 0.18).

Based on the petrographic composition and orientation of fragments, member 1 can be correlated with the Pechora till. In the Timan–Pechora–Vychegda region, the latter is characterized by high contents of local Mesozoic sedimentary rocks in the coarse-clastic material and the rigorous NE–SW orientation of elongated rock fragments (Andreicheva, 1992, 2002a). In addition, the Pechora till is marked by the siderite (10%)–garnet (21%)–epidote (28.7%) assemblage with high contents of amphiboles (~10%) and ilmenite (6.9%), as well as the predominance of pyrite over siderite in all samples.

Member 2
(Marine Sediments of the Rodionov Horizon, $Q^3_{II}r$)

Member 2 includes sediments of the beach, bar (outcrops 13-1, 13-3), intertidal (outcrop 6), and other facies accumulated in coastal and shallow-water littoral shelf zones (Fig. 4). The fine- and medium-grained sands of the beach and fore-beach zones (intertidal

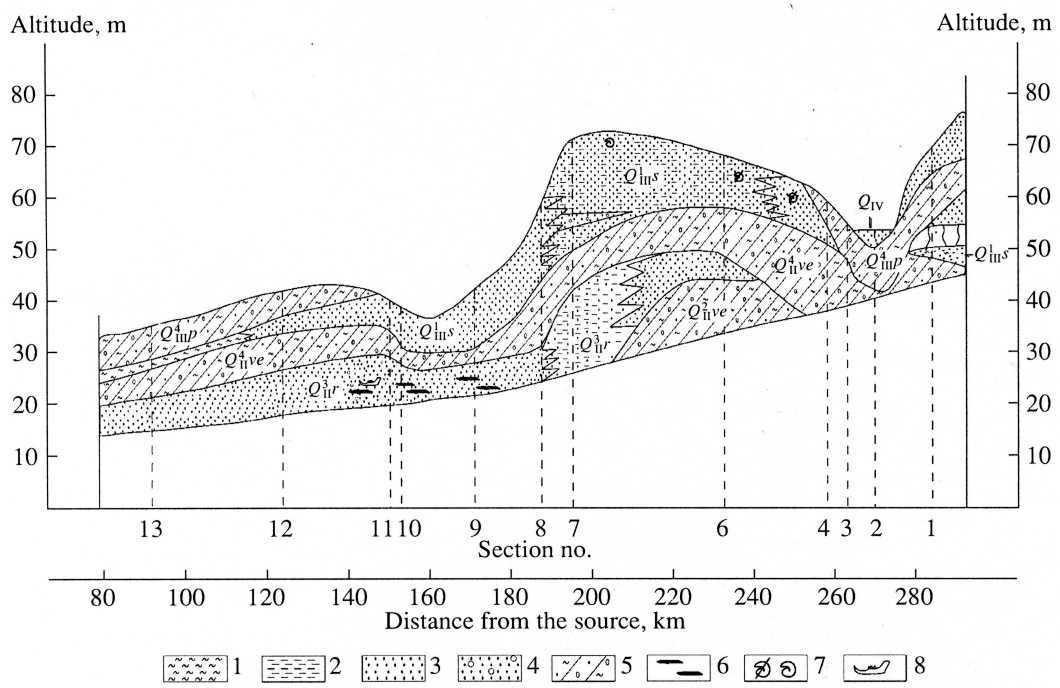


Fig. 2. Schematic geological section of Neopleistocene sediments in the Shapkina River valley. (1) Clay; (2) silt; (3) sand; (4) gravel and pebble; (5) till; (6) peat; (7) mollusk shells and fragments.

zone) and sediments of the shallow-water shelf are well washed and sorted (S_c = 0.52–0.71). The medium- and fine-grained sands with ripple marks usually grade upsection into the fine-layered clay. The sediments always contain fragments of mollusk shells and large redeposited shell detritus. The Rodionov age of these sediments is indicated by the fact that they overlie the Pechora moraine and underlie the Vychegda till.

We studied the mineralogy of beach sediments, as well as coastal-marine sand and gravel grading into coastal plain sediments of the Rodionov Horizon in the Shapkina River valley (Table 3). The content of the heavy fraction is as much as 1.4–1.72% in some places (average 0.94%). In littoral sediments, the content is substantially lower (0.35–0.65%). The heavy fraction content in the studied sediments is commonly governed by their grain size composition: the coarser-grained the sediments, the higher the content. Concentrations of components in mineral assemblages are variable even within a single outcrop. However, epidote predominates in all samples (24–41%). The content of amphibole is rather stable (12–14%). In contrast, the content of garnet is variable within both separate sections and single outcrop (8–20%). Sediments of the intertidal zone are depleted in epidote (24%) and titanium group minerals (4.8%), but enriched in garnet (20.2%), limonite (10.7%), and hematite (4.6%). Contents of other elements are presented in Table 3.

Member 3 (Alluvial, Lacustrine, and Lacustrine–Boggy Sediments of the Rodionov Horizon, $Q^3_{II}r$)

The age of Member 3 has been established by the palynological method at almost all outcrops and by the paleomicrotheriological method in some places. The palynological affiliation of Member 3 to the Rodionov Horizon is scrutinized in (Duryagina and Konovalenko, 1993). Based on the evolution level indicator of hoofed lemmings equal to 1.4 ± 2.2 (Kochev, 1993), sediments hosting remains of small mammals can reliably be dated back to the Rodionov time.

Alluvial sediments of the Rodionov Horizon exposed by two strippings (7-1 and 7-2) at outcrop 7 are represented by deltaic sediments (Fig. 5). The lower contact of this member (thickness >15m) is hidden beneath the river water. The sequence is composed of rhythmic alternation of well-sorted fine-grained lenticular and cross-bedded sand and silt (S_c = 0.52–0.57) with numerous varved interlayers of mud. These sediments are characterized by the moderate content of carbonates (3.1% in deltaic sediments and 4.6% in prodeltaic sediments). The heavy fraction content is not high. In deltaic sediments, the content is nearly two times higher (0.65%) than in the lower (previously submerged) part of the section (0.35%). The mineral assemblage is dominated by epidote (35% in the deltaic heavy fraction and 44% in the prodeltaic fraction). Contents of other minerals are appreciably lower: amphibole in the heavy fraction up to 17–18%, siderite

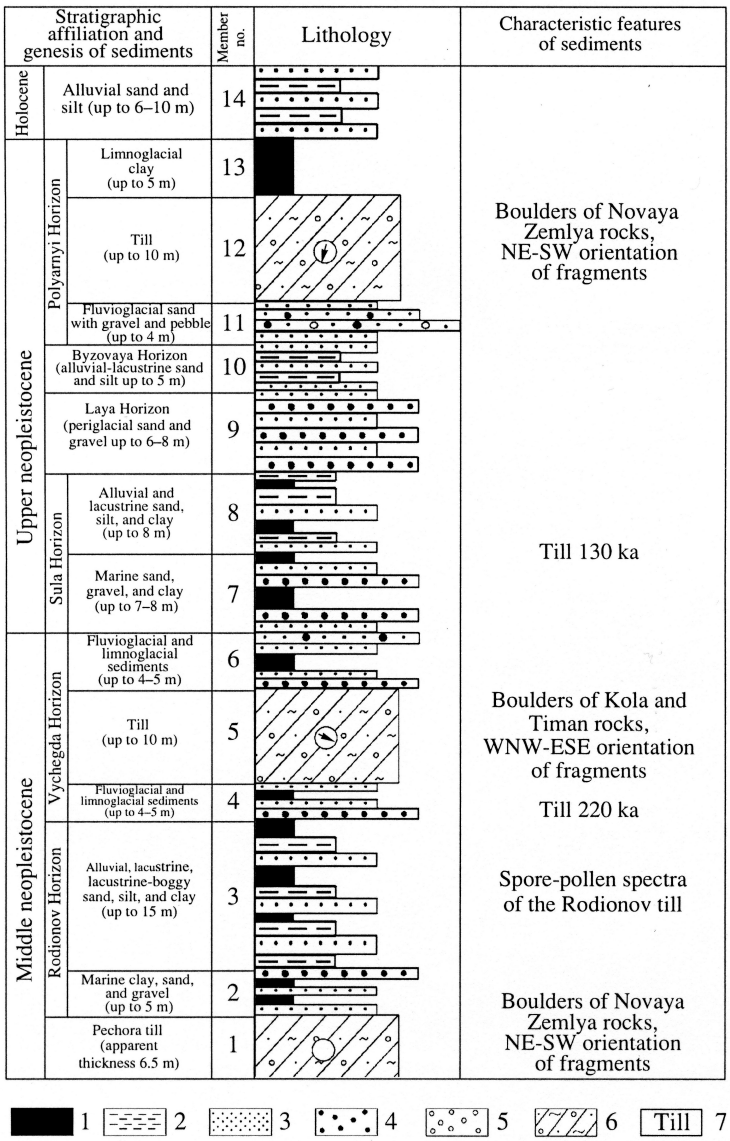


Fig. 3. Summary Neopleistocene section in the Shapkina River valley. (1) Clay; (2) silt; (3) sand; (4) gravel; (5) pebble; (6) till; (7) thermoluminescence dating of sediments.

11–14%, and garnet 4–10% (the lower and higher values characterize the subaqueous and subaerial sections, respectively).

Lacustrine and lacustrine–boggy sediments are exposed in the lower course of the Shapkina River (outcrops 9-1, 9-2, 10, 13-1). They consist of fine-grained horizontal-bedded sands with peat-bearing silt, clay, and loam. The degree of sorting varies from 0.22 to 0.61. The grain size of sediments shows reverse correlation with their sorting. For example, sand and sandy silt are significantly better sorted than clay, loam, and fine silt. Their Rodionov age in the middle course of the Shapkina River was determined by Guslitser et al. (1985). During investigations in the framework of the Russian-Norwegian PECHORA project, we found typical spore–pollen assemblages in these sediments. We also revealed that they overlie the periglacial cross-bedded gravel with the paleomicrotheriofauna in several lacustrine and lacustrine–boggy sections, suggesting their affiliation to the Rodionov Horizon.

Member 4 (Fluviogalcial and Limnoglacial Sediments of the Lower Vychegda, $Q_{II}^{4}vč^{1}$)

Sediments of Member 4 are exposed at outcrops 7, 9–11 in the middle and lower courses of the Shapkina River (Figs. 2, 3). At outcrop 7, the thick rhythmic

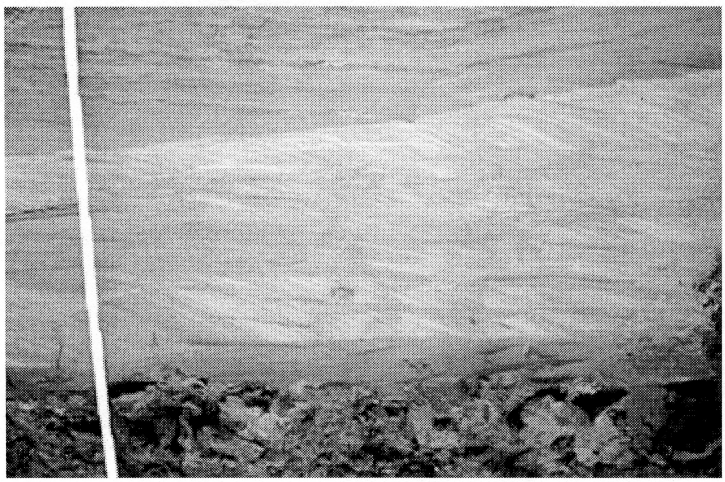


Fig. 4. Sediments with shallow-water ripple bedding (outcrop 13-1).



Fig. 5. Alternating deltaic sand and silt (Rodionov Horizon) beneath the Vychegda till (outcrop 7-1).

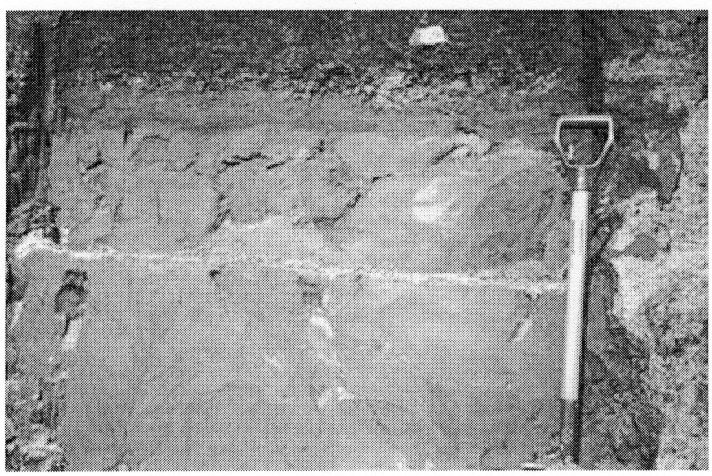


Fig. 6. Pre-Vychegda fluvioglacial sediments with pellets of bluish gray clayey loam (outcrop 11).

Table 2. Petrographic composition of coarse-clastic material from tills of the Shapkina River, %

Outcrop no.	Horizon index	Paleozoic dark gray and black limestones and dolomites	Paleozoic light gray and white limestones	Jurassic and Lower Cretaceous terrigenous rocks (proximal)	Permian and Triassic terrigenous rocks (transit)	Igneous and metamorphic rocks (distal)	Quartzites and quartzite sandstones (distal)
1a	$Q^4_{III}p$	30	20	22.5	12.5	2.5	12.5
2a	"	26	17.5	14.8	13.5	12.4	15.8
13-3*	"	18	27.9	21.7	9.9	9.9	12.6
Average $Q^4_{III}p$		24.7	21.8	19.7	12	8.3	13.4
1c	$Q^4_{II}vč$	1.8	22.8	15.4	22.7	30.1	7.2
3-1	"	12	28	22	18	8	12
4-4	"	16.5	22	19.8	17.5	17.6	6.6
4-6	"	15.7	23.6	17.6	16.7	15.4	11
7-1	"	10.5	20	14.7	16.6	17.3	20.9
8	"	3	22	24	14	29	8
10	"	6.7	30.2	23	16.6	18.3	5.2
11	"	5.5	30.7	18.7	14.2	19.9	11
12-1	"	14.8	31.8	20.4	12.8	8	12.4
12-2	"	17.1	30.6	20.8	13.5	7.2	10.8
12-6	"	17.4	26.1	21.7	14.5	8.7	11.6
12-pit	"	15.1	30	21.5	11.8	7.6	14
13-1	"	8.8	29.4	22.1	16.2	16.2	7.3
13-2	"	9.8	35.2	22	13.4	15.9	3.7
Average $Q^4_{II}vč$		11.3	27.6	20.3	15.4	15.1	10.3
6	$Q^2_{II}pč$	29.7	8.8	36.2	19.8	2.2	3.3

Note: (13-3*) Outcrop 13, stripping 3 in Tables 2–5.

Table 3. Average mineral composition of the heavy fraction of sediments of the Rodionov Horizon, %

Mineral	6	13-1	13-3	7-1	7-2
	Marine sediments			Alluvium (prodelta)	Alluvium (delta)
Heavy fraction content	0.94	0.94	0.52	0.35	0.65
Magnetite	0.5	0.4	0.1	0.8	0.7
Hematite	4.6	–	0.9	0.1	0.1
Ilmenite	5.3	14.8	2.5	1.2	3.1
Epidote	24	38.3	40.8	43.8	34.6
Amphibole	11.9	14.3	13.4	17.3	17.9
Garnet	20.2	10.7	8.3	4.1	10.4
Pyrite	0.1	2.2	2.8	0.4	1.2
Siderite	6.9	3.1	13	10.6	13.8
Zircon	2.8	2.5	2.2	3.6	3.8
Rutile	0.7	0.5	0.5	0.2	0.6
Titanite	1.7	3	2.1	1.1	2.4
Titanium mineral group	7.2	12.5	15	9.1	14.2
Kyanite	2.3	1.5	2	1.4	0.6
Staurolite	0.3	0.1	–	–	0.1
Sillimanite	–	–	–	–	0.1
Metamorphic mineral group	2.6	1.6	2	1.4	0.8
Tourmaline	1.3	1.3	0.3	0.7	0.7
Apatite	1.1	0.5	1.4	1.6	0.9
Pyroxene	2.7	2.1	3.2	1.1	1.1
Limonite	10.7	0.2	0.003	2.3	0.9

Note: Numerals in headings in Tables 3–5 designate outcrop numbers; (–) not detected.

sequence of deltaic sand and silt (Rodionov Horizon) underlies the Vychegda glacier complex with fluvioglacial and limnoglacial sediments at the base.

Fluviogalcial sediments (thickness 2 m) consists of pebblestones with a small amount of slightly rounded boulders in the sandy–gravelly filler. The sequence also includes interlayers or lenses of horizontal- and cross-bedded sand and gravel with small fragments of mollusk shells. The matrix is composed of iron hydroxides. The pebblestones are successively overlain with a distinct contact by layers of clayey silt (1 m) and coarse-grained sand. The silt is characterized by low sorting (S_c = 0.22–0.23) and carbonate content (2.0–2.1%). The subhorizontal wavy contact is emphasized by a thin interlayer of very compact gray clayey silt. At some coastal exposures along the Shapkina River bank below the mouth of the Vonda River, fluvioglacial sediments of the lower Vychegda section are composed of the brownish fine-grained sand with pellets of bluish gray loam up to 20–30 cm in size (Fig. 6). The loam has a ferruginated contact with the moderately sorted host rock (S_c = 0.49). The thickness of sediments does not exceed 2.5 m. The heavy fraction (average yield 0.76%) has the ilmenite (10%)–amphibole (11%)–garnet (23.6%)–epidote (32%) composition. The upper part of the fluvioglacial sequence is commonly brecciated and crosscut by differently oriented fractures related to the glaciodynamic impact of glacier. The sediments have exaration contact with the overlying Vychegda till, resulting in the formation of entrapment structures in the moraine sequence (Fig. 7).

The fluvioglacial sequence is overlain by dark gray, compact, ferruginated, and varved limnoglacial sediments (thickness 0.5 m) characterized by high sorting (S_c = 0.44–0.60) and clay content (up to 71%). The average particle size is 0.003–0.004 mm. The heavy fraction content is as much as 1%. The sediments are composed of epidote (~33%), amphibole (19.8%), garnet (16.5%), and titanium group minerals (12.7%) mainly represented by leucoxene (10%). The sequence is consistent in thickness and lateral direction and overlain by the Vychegda till.

Member 5 (Vychegda Till, Q_{II}^4 vč)

The Vychegda till, which is significantly more widespread than the Pechora variety, makes up the base or

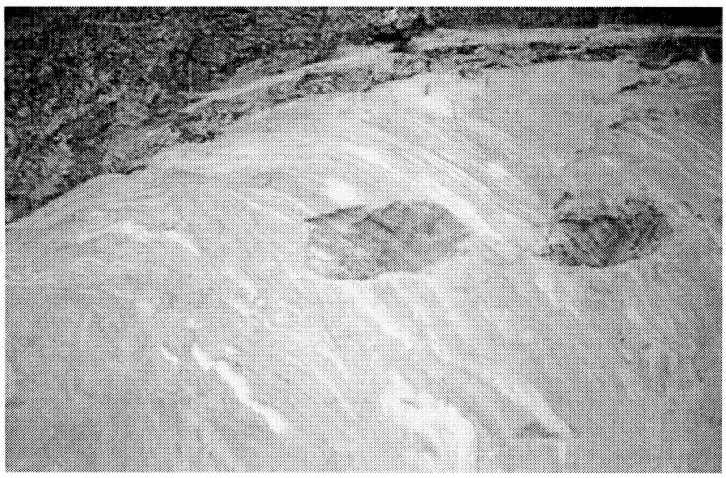


Fig. 7. Contact of the Vychegda till with the upright Rodionov sand (outcrop 12-2).

middle part of sections (Fig. 2). Its apparent thickness does not exceed 10 m. Till with the Vychegda-type petrographic characteristics was identified in several sections in the Shapkina River valley (outcrops 1, 3, 4, 7-13). This type of till is indicated by the presence of typical boulders from the Northwest terrigenous mineralogical province (Table 2) represented by nepheline syenites, granites (including the rapakivi variety), and granite gneisses of Fennoscandia, coupled with agate-bearing basalts of the northern Timan and Kanin peninsula. The till is generally characterized by high contents of carbonate rock fragments (25–48%, average 38.9%). However, their content in this area is lower than that in the overlying Polyarnyi till. Moreover, Paleozoic light-colored carbonates prevail over the dark-colored limestones and dolomites (27.6 and 11.3%, respectively). Local Mesozoic terrigenous and transit rocks account for 20.3 and 15.4%, respectively. In the Vychegda moraine, concentration of local Mesozoic rocks is nearly two times lower than in the Pechora till (36.2%). The majority of Vychegda till sections is characterized by higher contents of fragments of the distal igneous and metamorphic rocks (up to 30% in some places, average 15.1%). The quartzites and quartzite sandstones, which are alien for the Shapkina River valley, account for 10.3%. Petrographic evidence in favor for the relation of the Vychegda till with the Fennoscandian provenance is supported by the rather consistent southeastern orientation of elongate boulders.

In virtually all of the sections studied, the till is represented by the compact heavy loam (clay in some places) with structures of the entrapment of underlying sediments. Average contents of the gravelly-sandy, silty, and clayey fractions are equal to 18.4, 37.0, and 44.6%, respectively. All Vychegda till sections in the Shapkina River valley are characterized by rather high contents of the HCl (10%)-soluble material (5.2%). The sediments are characterized by a stable fine-grained composition (d_{av} = 0.020 mm) and low degree of sorting (S_c = 0.20).

The mineral composition of the heavy fraction of the Vychegda till is similar to that of the Chernaya River basin (Andreicheva, 2002b). The Vychegda till is characterized by the amphibole (10.1%)–garnet (16.9%)–epidote (24.5%) assemblage with a high total content (up to 6–11%) of minerals typical of Timan (rutile, titanite, leucoxene, kyanite, and staurolite) and a relatively low total content of siderite and pyrite (up to 21.5%). The heavy mineral content varies from 0.51 to 0.85% (average 0.69%).

Based on lithological and structural characteristics of the Vychegda till, this variety can correlate with the Vychegda moraine in the Timan–Pechora–Vychegda region (Andreicheva, 1992), the Moscovian till in the southern Astrakhan district (Andreicheva and Konovalenko, 1989), and the central Russian Plain (Andreicheva et al., 1997; Sudakova, 1990). The Vychegda age of the till is supported, in particular, by thermoluminescence datings carried out during the Russian-Norwegian PECHORA project. At outcrop 7, the moraine-underlying marine sand is estimated at 230 ± 20 ka, whereas the moraine-overlying lacustrine sand and silt are estimated at 130 ± 12 ka. The confinement of till between the dated sequences is unambiguous evidence in favor of its Vychegda age.

Member 6 (Fluvioglacial and Limnoglacial Sediments of the Upper Vychegda Section, $Q_{II}^4 vč^3$)

Fluvioglacial sediments overlying the Vychegda till are exposed at outcrop 4 on the right bank of the Shapkina River 8.5 km northeast of the mouth of the Kamavis Creek. The 3-m-thick sequence is composed of yellowish gray fine-grained compact nonlayered sand. The sequence also includes typical patches and lenses of

Table 4. Average mineral composition of the heavy fraction of fluvioglacial sediments, %

Mineral	7-1	13-1	9-1	10	11	4-3
	Q_{II}^4 vč^1	Q_{II}^4 vč^1	Q_{II}^4 vč^3	Q_{II}^4 vč^3	Q_{II}^4 vč^3	Q_{III}^4 p^1
Heavy fraction contentfraction content	0.99	0.77	3	0.95	0.76	1.16
Magnetite	0.6	0.1	0.8	0.3	0.4	0.7
Hematite	–	–	1.1	0.8	0.7	0.4
Ilmenite	0.9	9.2	10.3	7.9	10.2	10.1
Epidote	33.5	34.3	16.2	38.1	29.6	36.4
Amphibole	19.8	11.9	8.4	8.9	10.2	8.9
Garnet	16.5	23.6	28.2	22.7	25.7	23.6
Pyrite	–	0.1	10	2.4	3.3	0.9
Siderite	0.7	0.4	7.2	5.2	0.2	11.1
Zircon	3.5	4	2.5	2.3	3.1	0.7
Rutile	0.5	0.6	1.5	0.1	0.3	0.1
Titanite	2.3	2.9	2.4	2.2	4.8	0.9
Leucoxene	9.9	5	1.9	4.4	5	2.8
Titanium mineral group	12.7	8.5	5.8	6.7	10.1	3.8
Kyanite	1.8	1.5	1	0.7	1.9	0.1
Staurolite	0.3	0.3	–	–	–	0.6
Metamorphic mineral group	2.1	1.9	1	0.7	1.9	0.7
Tourmaline	0.5	1.1	0.9	1.9	1.3	0.7
Apatite	1.1	1.3	0.6	0.6	0.3	0.2
Pyroxene	2.4	2.5	1.7	1.5	1.7	0.7
Limonite	5.4	0.9	0.3	0.8	0.3	0.7

Note: Numerals in subheadings designate horizon indices.

medium- and coarse-grained sand with rare fine pebble, as well as dark gray sandy loam and loamy sand that are ferruginated at the contact with the host rock. The sediments are characterized by relatively well sorting in the lower part of the sequence (S_c = 0.53) and poor sorting in the upper part (S_c = 0.32), suggesting their formation in ephemeral currents of the fluvioglacial type. Sediments virtually similar to those described above are also exposed on the bank of the Shapkina River. Fluvioglacial sequences of the Shapkina River valley contain rocks with a highly variable grain size distribution ranging from the unsorted sandy silt (S_c = 0.23–0.27) with rare gravel inclusions to the poorly sorted sand (S_c = 0.3) with a high content of gravel (16.4%) and the fine-grained moderately sorted sand (S_c = 0.34–0.54).

The mineral composition of the heavy fraction of fluvioglacial sediments testifies to its certain inheritance from the underlying Vychegda till (Table 4).

In some places, the fluvioglacial sediments underlie limnoglacial sediments represented by the fine-grained varved clay and silt. Fine-grained sand (with horizontal bedding and pebbles) derived from the coastal area of a paleolake is also observed. These sediments could be formed during the melting of the Vychegda glacier. They are characterized by gray color, ferruginated patches, massive structure, high content of the clayey fraction (up to 71%), and variable sorting (S_c = 0.23–0.52).

Member 7 (Marine Sediments of the Sula Horizon, $Q_{III}^1 s$)

Member 7 is represented by facies-variable sediments of the shallow-water shelf (outcrops 9-2, 9-3, 13-3), beach sediments (outcrops 4-2, 12-4, 12-5, 12-6), and relatively deep-water facies (outcrop 1).

The beach sediments show the best sorting (S_c = 0.55–0.73), while sediments of the shallow-water shelf are virtually unsorted (S_c = 0.16–0.19) and enriched in carbonates (6.6–7.5%).

The content of heavy minerals in the Sula beach sediments varies from 0.3 to 1.13% (Table 5). The heavy fraction content is more stable in sediments of the shallow-water shelf (0.66–0.93%). The marine sediments are composed of epidote, garnet, and amphibole. Relative to the shallow-water shelf facies, the beach facies

Table 5. Average mineral composition of the heavy fraction of marine sandy loams, %

Mineral	9-2	9-3	13-3	4-2	12-4	12-5	12-6
	Shallow-water shelf			Beach			
Heavy fraction content	1.19	0.93	0.66	1.13	0.3	0.6	0.62
Magnetite	1.2	0.2	0.6	0.5	0.4	0.4	0.3
Hematite	0.7	1.1	0.4	0.5	0.2	0.7	0.6
Ilmenite	8	5.8	1.5	10.8	9.3	6.1	5.3
Epidote	22.3	22.4	30.1	24.5	33.9	20.8	20.7
Amphibole	7.8	10.3	11.6	10.3	16.9	19.4	19.1
Garnet	14.6	16.4	18.2	29.1	13.5	14.3	16.8
Pyrite	14.4	12.8	15.3	1.2	1.5	2.1	2
Siderite	18.9	16.5	9	5.6	1.4	12.3	4.5
Zircon	3.6	3.9	3.9	4	4.8	0.5	0.3
Rutile	1.1	0.6	0.5	1.1	0.6	0.6	1.1
Titanite	1.4	1.3	2.3	3.1	2.3	3.1	3.5
Titanium mineral group	6.5	8.3	7.4	13	14.3	11.1	11.4
Kyanite	0.8	1	0.6	1.6	3.6	4.6	1.4
Staurolite	0.1	0.2	–	0.2	–	0.9	0.2
Sillimanite	–	–	–	–	–	0.1	0.7
Metamorphic mineral group	0.9	1.3	0.6	1.8	3.6	5.6	2.3
Tourmaline	0.2	0.4	0.8	1.4	0.8	0.8	0.7
Apatite	0.5	2.4	0.8	0.6	1.1	4.7	3.8
Pyroxene	0.5	1	0.6	1	1.9	3.8	3.9
Limonite	0.6	0.2	1	2.3	0.7	1	7.6

is characterized by more than 1.5 times higher content of amphiboles and nearly two times higher contents of titanite and leucoxene. The total content of titanium group minerals and metamorphic minerals (kyanite, staurolite, and sillimanite) is also nearly two times higher. Sediments of the shallow-water shelf are enriched in pyrite and siderite (14.2 and 14.8%, respectively), which account for only a few percents of the heavy fraction.

Member 8 (Alluvial and Lacustrine Sediments of the Sula Horizon, $Q^1_{III}s$)

Member 8 is only found in two sections. At outcrop 11, **alluvial** sediments of the Sula Horizon overlie the upper Vychegda limnoglacial and solifluction sediments. The 5-m-thick sequence consists of the fine-grained sand and gravel with wedge-shaped offset bedding at the base, cross bedding in the middle part, and horizontal- and cross-bedding in the upper part.

At outcrop 7-3, the Sula Horizon is composed of **lacustrine** sandy–silty sediments (up to 8 m) with a variable degree of sorting (S_c = 0.35–0.71). Their bedding is fine horizontal (varved in some places), lenticular (with oblique unidirectional laminas inside the lenses), and cross-wavy (ripple marks). The textural–structural attributes of sediments suggest the probability of their formation in an open lake of moderate dimension. The heavy fraction (no more than 0.49%) includes epidote (37.4%), titanium group minerals (14%), limonite (10.1%), siderite (8%), and zircon (5.2%).

Member 9 (Periglacial Alluvium of the Laya Age, $Q^2_{III}l$)

Sediments of Member 9 are only exposed in two sections (outcrops 8, 9-1). They consist of the fine- and coarse-grained cross-wavy sand and gravel (Fig. 8). These sediments grade upsection into the fine-grained obscurely bedded and massive sediments with large ice wedges (more than 1 m wide and up to 7 m long in some places). The sediments are well washed and differently sorted (S_c = 0.41–0.57). The heavy fraction (mainly, garnet and epidote) varies from 0.76 to 1.47%. The heavy fraction of the periglacial alluvium from this area is characterized by the minimum epidote (24%) and maximum siderite (up to 18%) contents in the Timan–Pechora–Vychegda region. The epidote content

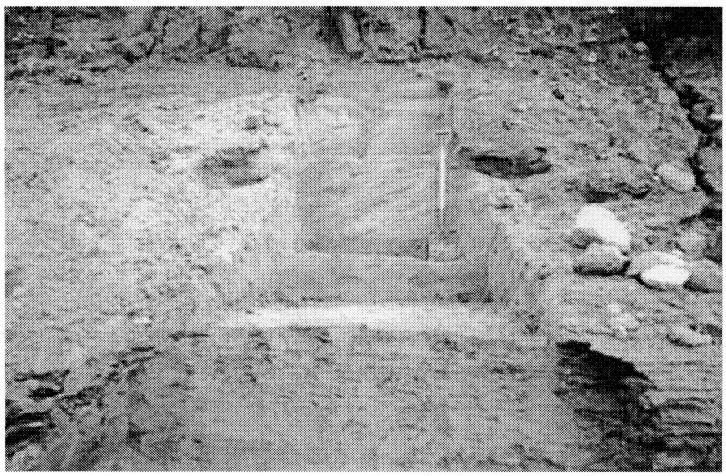


Fig. 8. The Laya cross-bedded periglacial–alluvial sand with pseudomorphs formed after ice wedges (outcrop 11).

increases in the northeastern direction (Andreicheva, 2002a).

Member 10 (Byzovaya Alluvium, $Q^3_{III}b$)

Member 10 is only exposed in one section (outcrop 8). The alluvial sequence is composed of horizontal and subhorizontal intercalation of fine-grained sand and yellowish brown silt. Upward the section, the alluvium is characterized by the gradual decrease in grain size, presence of fine clay lenses with plant remains, better sorting, and low content of carbonates (average 1.9%).

Member 11 (Lower Polyarnyi Fluvioglacial Sediments, $Q^4_{III}p^1$)

Member 11 exposed at outcrop 4-3 is composed of poorly sorted (S_c = 0.34%) fine-grained very compact (d_{av} = 0.134 mm) sand with pebbles and gravel (up to 7%). Sediments of this member are bedded in some places, but the bedding is crumpled (up to the point of upright standing) and emphasized by ferrugination. The sequence (~4 m thick) has clear exaration contact with the overlying till. The content of heavy minerals is 1.16%. The mineral assemblage is as follows (%): epidote 36.4, garnet 24.6, siderite 11.1, ilmenite 10.1, and leucoxene 2.8. The content of other minerals does not exceed 1%.

Member 12 (Polyarnyi Till, $Q^4_{III}p$)

Sediments of this member have limited distribution because the Late Valdaian Glacier entered the Shapkina River valley as two lobes. One lobe overlapped the upper course of the river (mouth of the Vesniyu River and its outskirts), while the second lobe overlapped the lower course of this river. The Polyarnyi till is exposed at the upper (outcrops 1, 2, 4-1) and lower (outcrops 12-3, 12-4, 12-5, 12-6, 13-1, 13-3) courses of the Shapkina River. The till is 5–10 m thick.

The till is composed of gravelly–sandy (20.4%), silty (44.3%), and clayey (35.3%) fractions. Relative to the Vychegda till, the Polyarnyi variety has a finer-grained composition (d_{av} = 0.018 mm) in the majority of sections. The sediments are virtually unsorted (S_c = 0.19). The total carbonate content is slightly higher (7.5%) than that in the Vychegda till.

Elongate fragments in the Polyarnyi till of the Shapkina River basin are differently oriented, e.g., along the NE–SW direction in the blanket moraine at the upper course of the river and along the NW–SE direction at the lower course. This feature is prominent in the petrographic composition of boulders and pebbles (Table 2). Carbonate rocks account for as much as 46.5% of the clastic material. They are mostly represented by Paleozoic dark gray and black limestones and dolomites at the upper course of the river and by light-colored limestones at the lower course. Proximal Mesozoic sandstones, siltstones, mudstones, and others make up 19.7%, whereas the distal sedimentary rocks account for 12% of the clastic material. The content of fragments of igneous and metamorphic rocks is 8.3%, while the content of quartzites and quartzite sandstones is 13.4%. Fragments of pink marbleized crinoid–bryozoan limestones, index rocks of Novaya Zemlya, are pervasive at the upper course of the river.

The content of heavy minerals varies from 0.5 to 0.81% (0.21% at outcrop 4). Like in the Chernaya River basin (Andreicheva, 2002b), the mineral assemblage in the Shapkina River basin is mainly composed of epidote (23.2%), garnet (16.1%), siderite (14.8%), and amphibole (11.5%). However, the total content of pyrite and siderite is considerably lower in this basin.

Table 6. Lithology of tills in the Shapkina River basin

Horizon index	Rock group, %						Guide boulders and other characteristic rocks	Fragment orientation	Characteristic mineral assemblages and minerals (content is given in parentheses)	d_{av}
	I	II	III	IV	V	VI				
Q^4_{III} p upper course	28	18.8	18.7	13	7.5	14.2	Pink bryozoan limestones from Novaya Zemlya. Dark-colored carbonate rocks prevail	NNE–SSW	Amphibole (10)-siderite (16)-garnet (17.1)-epidote (24)	0.018
Q^4_{III} p lower course	18	27.9	21.7	9.9	9.1	12.6	Basalts with agate from Timan. Light-colored limestones prevail	NNW–SSE	Amphibole (12.7)-siderite (13.3)-garnet (14.8)-epidote (22.2)	0.019
Q^4_{II} vč	11.3	27.6	20.3	15.4	15.1	10.3	Crystalline rocks of Fennoscandia. Timan basalts with Permian agate, opoka, marl, and orange sandstone. Light-colored limestones prevail	WNW–ESE	Amphibole (10.4)-garnet (18)-epidote (26.1)	0.020
Q^2_{II} pč	27.9	8.8	36.2	19.8	2.2	3.3	Pink bryozoan limestones. Dark-colored carbonate and local rocks prevail	NE–SW	Siderite (10)-garnet (21)-epidote (28.7)	0.012

Note: (I) Paleozoic dark gray and black limestones and dolomites; (II) Paleozoic light gray and white limestones; (III) Jurassic and Lower Cretaceous terrigenous rocks (proximal); (IV) Permian and Triassic terrigenous rocks (transit); (V) Igneous and metamorphic rocks (distal); (VI) Quartzites and quartzite sandstones (distal).

Moreover, siderite continues to prevail in the majority of Polyarnyi till sections.

Member 13 (Upper Polyarnyi Limnoglacial Sediments, $Q^4_{III}p^3$)

Member 13 was probably accumulated during degradation of the Polyarnyi glacial sheet. Sediments of this member are only found in one section (outcrop 1-c). They overlie the Polyarnyi moraine as a 5-m-thick sequence of dark gray elastic clay (d_{av} = 0.010 mm) with varved bedding. The sediments are intensely ferruginated and deformed, probably, owing to landslides. The total carbonate content in the varved clays is 5.8%, and the average S_c value is 0.49.

Member 14 (Holocene Sediments, Q_{IV})

Holocene sediments are exposed in upper sections of outcrops. In some places, they make up a terrace (6–10 m thick) above the floodplain and extend more or les continuously along the river. The sequence is composed of typical alluvium with regular structural variations along the vertical section. The cyclothems become thinner upward the section. The average grain size composition indicates a rather low content of carbonates (0.6–2.2%) and variable degree of sorting of the fine-grained material (S_c = 0.39–0.71). The heavy fraction content does not exceed 0.72%. The mineral assemblage is mainly composed of epidote (34.6%), garnet (23.6%), and amphibole (9.4%). The titanium group minerals make up 11.2%, including leucoxene (6.2%) and titanite (4.8%). The content of other minerals varies from 0.*n* to *n*%.

CONCLUSIONS

Study of lithostratigraphic relations of sediments in the Neopleistocene summary section has made it possible to identify all major stratigraphic horizons in the Shapkina River basin. Not dwelling on the lower part of the Neopleistocene section, which is well known from borehole data, let us note the basic conclusions concerning the middle–upper Neopleistocene lithology, stratigraphy, and paleogeography in the study region.

The Shapkina River basin incorporates three glacial horizons. Table 6 presents lithological characteristics of these tills. The Pechora till (Member 1) only identified at one outcrop was accumulated during the motion of sheet glacier from the Ural–Paikhoi–Novaya Zemlya glaciation center in the northeast. Correlation with the Pechora (Dnieper) till is exclusively based on the mineralogical–petrographic similarity of the clastic material in moraine sediments and the NE–SW orientation of elongate rock fragments.

The most widespread glacial horizon is the Vychegda till (Member 5). The orientation of elongate fragments and the presence of Fennoscandian and northern Timan index rocks testify to the input of clastic material from the Northwestern terrigenous–mineralogical provenance (Baturin, 1947). In some sections, the Vychegda till alternates with limnoglacial clays, fluvioglacial and periglacial–alluvial sands, and pebble–gravel material from both under- and overlying units.

The Polyarnyi glacial horizon (Member 12) is only developed in some places of the Shapkina River valley. Orientation and petrographic features of rock fragments indicate that the Polyarnyi till formed at the upper course of the river, where the NE- to SW-oriented elongate fragments contain the marbleized Novaya Zemlya crinoid–bryozoan (index) limestones delivered from the Northeastern terrigenous–mineralogical provenance. The Polyarnyi moraine formed at the lower course of the Shapkina River due to the probable input of terrigenous material from the Scandinavian glaciation center. In addition to the moraine, fluvioglacial limnoglacial sediments are also present in this area.

The Rodionov Horizon (members 2, 3), exposed beneath the Vychegda till along the Shapkina River bank, is composed of coastal-marine sediments with typical structural features of beach and fore-beach zones. Sediments of the shallow-water shelf, lacustrine, and lacustrine–boggy facies are also present. The Shapkina River basin primarily accumulated marine terrigenous sediments under conditions of the Polar cold humid climate with suppressed chemogenic and organogenic sedimentation.

The Sula Horizon (members 7, 8) is also composed of coastal-marine, alluvial, and lacustrine sediments. Their formation is mainly related to erosion of the Vychegda till delivered from the Fennoscandian glaciation center. The Sula moraine becomes more enriched in minerals derived from the Northwestern terrigenous–mineralogical provenance in the western direction.

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