The Formation of the Upper Vendian – Middle Cambrian Clay Strata of Subclint Area

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Abstract. Silt-clay strata of Upper Vendian (Kotlinskian horizon) and Lower Cambrian age can be traced along the denudation ledge of Ladoga-Baltic clint. The study area is located in subclint area where sediments were studied in scattered shallow outcrops and wells from the estuary of the river Voronka in the west to the river Tosno in the south-eastern part of the clint ledge. Deposits are related to Vasileostrovskian (r. Chernaya) and Voronkovskian (r. Voronka) suites of Upper Vendian, Lomonosovskian (r. Kovash) and Siverskian (r. Tosno) suites of Lower Cambrian. Sedimentation occurred most likely in the lagoon environment periodically alternating with coastal shallow environment. Accumulation of thick bottom sediments is possibly due to the active areal physical weathering on the adjacent land.

For a number of lithological and petrographic features, close chemical composition, X-ray modeling of clay minerals, as well as findings of similar prokaryote residues may be assumed that the accumulation of boundary clay strata at the boundary of the Vendian and Cambrian subclint area occurred without a long break in the studied area.

Key words: clay strata, subclint area, sedimentation, Upper Vendian, Lower Cambrian, lithological and petrographic features, chemical composition.

DOI: 10.18599/grs.18.2.9

For citation: Gagen-Torn O.Ya. The Formation of the Upper Vendian – Middle Cambrian Clay Strata of Subclint Area. *Georesursy = Georesources*. 2016. V. 18. No. 2. Pp. 120-126. DOI: 10.18599/grs.18.2.9

Clay deposits of Upper Vendian-Lower Cambrian are traced in a narrow strip along the ledge of the Baltic-Ladoga limestone cliff, which stretches along the southern coast of the Gulf of Finland. Despite the long study history starting from works of A.A. Inostrantsev and F.B. Shmidt, B.S. Sokolov and K. Mene to N.A. Volkova and V.N. Podkovyrov et al., the matter of age and origin of boundary clay strata in Vendian-Cambrian deposits in the northwest of Russian platform remains unsolved.

Vendian-Cambrian deposits are represented by silty-clay strata, studied by the author in disparate thin sections (natural outcrops are very rare) and penetrated by wells (materials of A.S. Yanovsky from St. Petersburg exploration company). We also used materials of A.M. Nikulenkov (Faculty of Geography and Geoecology of St. Petersburg State University) and core from wells drilled on the territory of St. Petersburg atomic power station. We studied the Lower Cambrian deposits attributable to the Lomonosovskian formation in small outcrops on the river Kovash and deposits of Siverskian formation (‘blue clay’) in the clint ledge in the stratigraphic sections of the Cambrian-Ordovician on the river Tosno.

Schematic sections (Fig. 1) were compared by lithologic features using materials of hydrogeological survey of A. Yanovsky and legend of Ilmenskian series of sheets (Yanovsky, 1999). Materials require further micropaleontological research and age correlation.

In the analysis of some sections we used descriptions of thin sections composed by V.V. Kostyleva. The definitions of cyanobacteria are made by V.N. Sergeyev (previously not carried out on test sections); V.V Krupskaya participated in modeling clay mineral radiographs (Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry of the Russian Academy of Sciences). The materials used in the study are not always clear: the core description of most wells is taken from production reports, and stratigraphic units allocated by different authors are not always comparable, for example, in the columns of wells on the territory of St. Petersburg atomic power station voronkovskian formation is not allocated.

Vasileostrovskian Laminaria clay observed in the core of well drilled in the yard of the former Geolkom (current All-Russian Geological Research Institute) (Yanishevsky, 1939) and exposed at the museum of A.P. Karpinsky Russian Geological Research Institute, outwardly indistinguishable from the Lower Cambrian clays of Lomonosovskian formation and ‘blue’ clay of Lower Cambrian Siverskian formation. The outward similarity of the above clays is confirmed by the same particle size distribution and physical-mechanical properties, studied in research to create underground burial of radioactive wastes in them (Anderson et al., 2006).

Stratigraphic referencing of the studied section

Vendian. Upper Section.

Kotlinskian Horizon. Vasileoostrovskian Formation

One of the key objects for understanding the structure is a natural outcrop in the river Chernaya near the village B. Izhora (section ‘I’; Fig. 2).

In the nip of the left bank of the river Chernaya in the outcrop with height of about 10 m and length of about 20 m Upper Vendian (Upper Kotlinskian) clay is observed of blue and greenish-gray color, ocherous silty with horizontal and wavy bedding, underlined by layers of silt material, pinky gray color with laminaria films on the bedding surfaces associated with transformation of organic matter.

Laminaria clay is thin, less massive microstructure, tape thin-layered texture, due to the alternation of dark gray clay and light-gray siltstone and coarse pelitic stratums (0.1-3 mm). The silt layers have flat lenticular siderite nodules.

There are interlayers with ferruginized clayey siltstone and unevenly positioned silt material. Probably interlayers are cracking crust formed after the break and consolidation of the underlying sediments.

Lens silt material is visible in kaolin clay substrate. The clay-silty substrate has ferruginated remains of fossil prokaryotic cells, forming a chain by determination of V.N. Sergeev Bavlinella taveolata Schepeleva (1962?), Ostiana cf. microcystis Hermann (1976).

Currently, the age of the observable Vendian part of the section is confirmed by definitions of Vendotaenia antiqna Gnilovskaya.

Vasileostrovskian clays, penetrated by well C-5, have remains of prokaryotes in thin sections, determined by

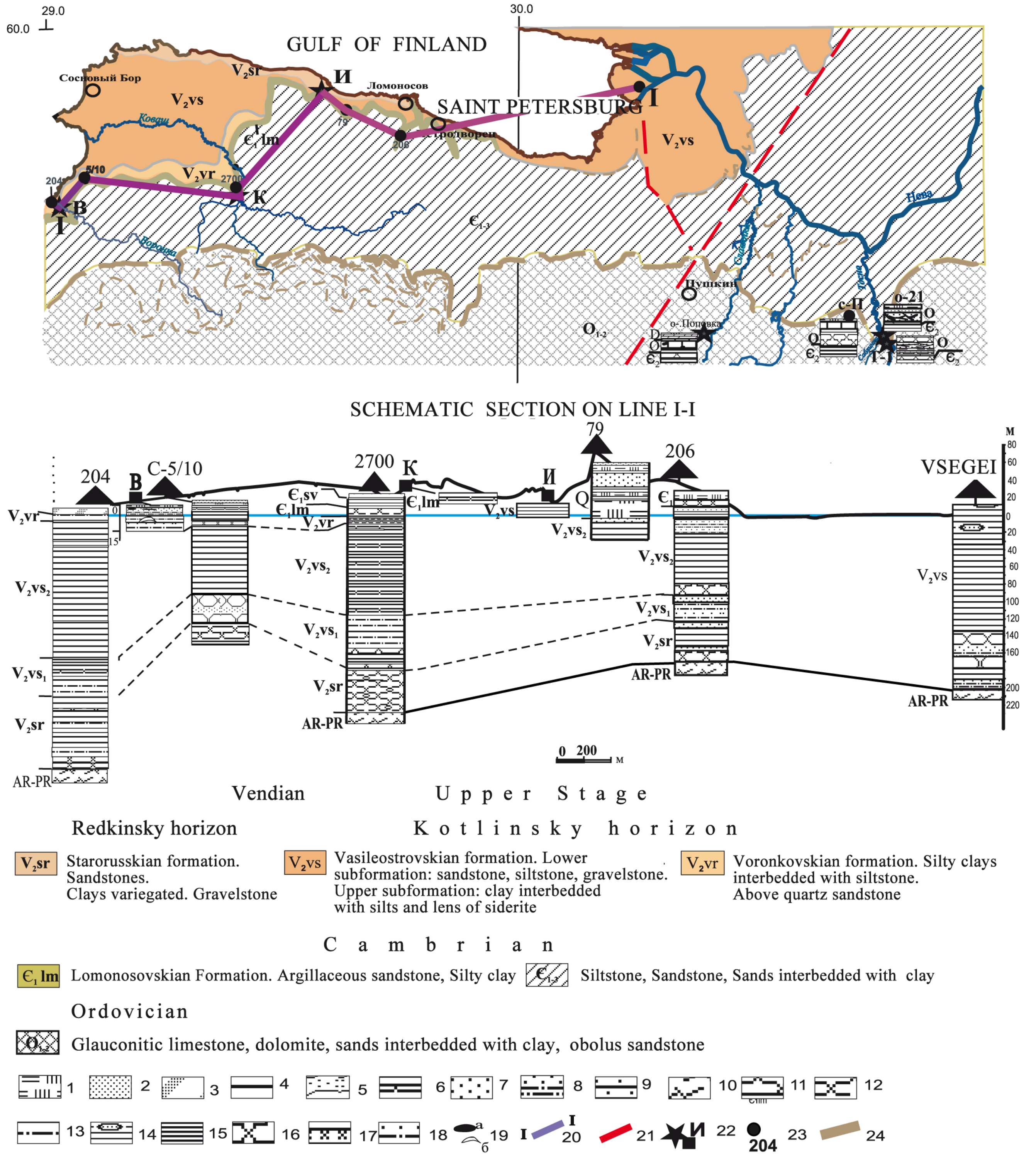


Fig. 1. Geological map of the studied area (using materials of A.S. Yanovsky). 1 – Clay remolded ('blue') with boulders, 2 – Sands uneven-grained, 3 – Sandy soil, 4 – Dictyonema shale, 5 – Sands interbedded with sandstones, 6 – Clay interbedded with sandstones, 7 – Sands with lenses of ferruginous sandstone, 8 – Sands and silts with interbedded sandstones, 9 – Silt clay, 10 – Gneiss, granodiorite, 11 – Sandstones uneven-grained, interbedded with clay, 12 – Sandstones uneven-grained, 13 – Alternating argillites, mica-kaolinite with argillaceous siltstone, 14 – Clay lenses of quartz sand, 15 – Clay thin-bedded, 16 – Sandstones interbedded with siltstone, 17 – Clay with silty and siderite layers, 18 – Siltstone interbedded with silts, 19 – Lenses a- siderite, b – lepidocrocite, 20 – the section line, 21 – faults, 22 – outcrops, 23 – wells, 24 – boundary of the Ladoga-Baltic clint.

V.N. Sergeyev as pterospermopsimorphic, spheromorphic, colonial coccoid forms. In this section remains of algae were found in clays.

Found remains of prokaryotes indicate the presence of free oxygen in the bottom muds, possibly due to activation of weathering processes on the adjacent land.

The overlying silt-clay strata of Upper Vendian attributable to the Voronkovskian formation (Yanovsky, 1999) and extending in a westerly direction to the northern Estonia, is exposed near the mouth of the river Voronka (section ‘B-1’; Fig. 2).

In the fine-grained bluish-gray sandstones, strong (below the water line), there are compacted greenish and bluish-gray clay with laminaria ferruginated films. This part of the section may be referred to Vasileostrovskian formation at finding of M. Leonov (Paleontological Institute of the Russian Academy of Sciences) Vendotaenia antiqua. The overlying sediments are likely to be voronkovskian.

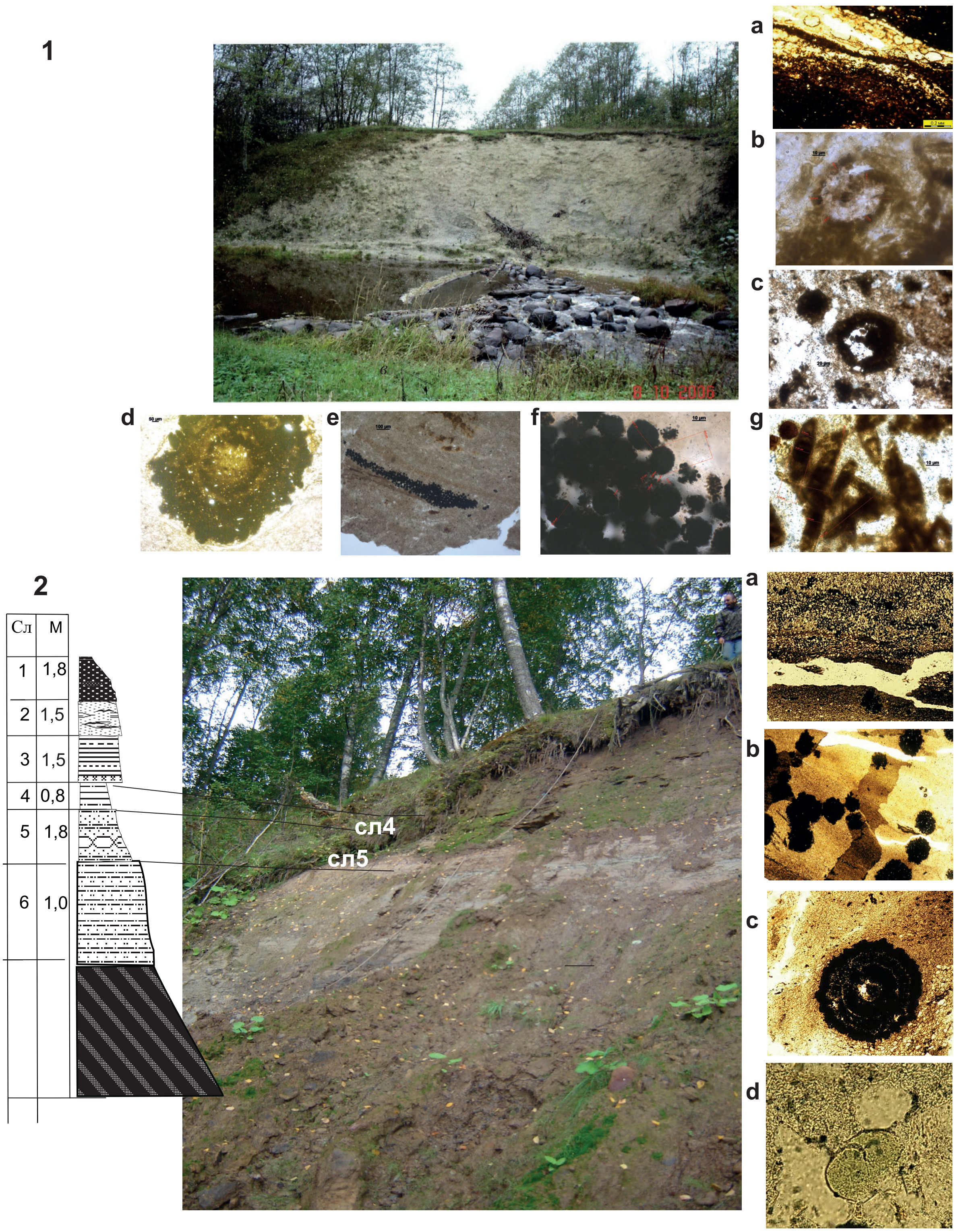


Fig. 2. Section of Kotlinskian deposits: 1 – Vasileostrovskian formation on the river Chernaya (I), a-microbial mat; b – Siphorophycus Kestron Schopf, 1968, c-Paleo Palaeolyngbya cf.P.Basghoorniana, d, e, f – pyrite along colonies of cyanobacteria, g – Oscillatoriopsis aff.O.meding. 2 – Voronkovskian formation on the river Voronka (B-1): a – siltstone layers alternating with layers of siltstone clay; b – Silty clay with mud-eaters traces and glandular inclusions; c – ferrigenous inclusions; g – globules of glauconite in sandstone.

Voronkovskian Formation

Pack of centimeter-decimeter interbedded silty mudstone, mica-kaolinite clay, micaceous siltstone with occasional fine sand.

Sands are weakly ochreous with interbedded sandstones ferruginized to 15 cm thick and lenticular bluish streaks of pink silty clay with horizontal wavy discontinuous layering of 1-3 cm thick. In silt layers there are flattened lenticular and large up to 15 cm siderite nodules destroyed with black glandular rim.

Up the section silt thickness increases.

In the upper part of the section there is a pack of (thickness 0.8 m) clays of blue, purple and yellow shades with lenticular sand layers (less than a centimeter). Pack is crowned with interbedded argillaceous rocks of bright yellow color, and is clearly seen on the outcrop.

The presence of lepidocrocite, whose formation (Chukhrov et al., 1973) involves the dissolution of siderite, when iron goes into solution in the form of $Fe(HCO_3)_2$, ochreous rocks on silt layers, and ochreous and black halos of iron hydroxides on the periphery of siderite nodules indicate the possible formation of rocks pack in subaerial conditions and may be indicative of the existence of the weathering crust, described in Vendian sections of Baltic (Bessonova et al, 1980;. Mene, Pirrus, 1969) and observed in wells 204 and 2700.

Above there is a pack of whitish quartz, fine sand and silt clay with thin centimeter lenticular streaks of rust (ferruginized) sandstones. The pack is covered by Quaternary boulder loams.

According to M. Leonov (Paleontological Institute of the Russian Academy of Sciences), in clays at the water's edge the remains are found of Vendotaenia antiqua Gnilovskaya (1974) typical for sediment of Vendian Kotlinskian horizon (Ediacaria) in the East European platform (other finds of fossil remains are not found in these outcrops). In other sections of border deposits Planolites and N.A. Volkova acritarchs were recently discovered and described.

Quaternary sediments close the overlying part of section in the studied area. Natural outcrops with contact of Vasileostrovskian and Lomonosovskian deposits are not there, it was opened by wells, but the core has not been preserved and it is not available (wells on the territory of Leningrad atomic power station).

Cambrian. Lower Section
Lomonosovskian Formation

According to drilling within the city of Lomonosov (well 206), this part of the section, above the gray clay, is represented by sands, poorly cemented by sandstones and clays of Lomonosovskian Formation of the Lower Cambrian. Sandstone of Lomonosovskian Formation, observed in wells 206 and P-5 and exposures "K-1" and "K-2" (Fig. 1), may be attributed to Voronkovskian.

In the middle stream of the river Kovash in scattered small outcrops (up to 2 m thick) silty clay is exposed that looks very similar to voronkovskian.

Clay lies monoclinally with a gentle fall in the southeast dipping towards the northwest wing of the Moscow syncline at angles of 9-12°.

Blue plastic and dense clay has unclear bedding, and shelly conchoidal fracture. The surfaces of the bedding are 'sprinkled' with leaves of mica (mm). Closer to the water's edge blue color becomes more intense.

In some interlayers greenish tint appear due to glauconite observed in thin sections, and confined to the silt interlayers in clay. On the surfaces of the bedding ferruginized film (mm), possibly laminaria remains and ocher spots are observed. Surface of bedding is smooth. At 1 m from the base interlayer (3-5 cm) is traced of blue-gray fine-grained sandstones with thin horizontal stratification (mm), accentuated by dark gray layers every 3-5 mm. Bedding surfaces of sandstone are covered with ferruginous films, in some portions ripple marks are observed with shallow ridges with a height of up to 2 mm.

By particle size distribution clay can be attributed to silt. In clays of section 'K-1' A.Yu. Ivantsov found Sabellidites cambriensis Janischevskii.

Siverskian Formation

In the sections of river Tosno and near the mouth of the river Sablinka clay underlying sands of Sablinskian suite was studied (section "T-1" and repeatedly described section "Outcrop 21", Fig. 1). Clay is blue, when wet green, homogeneous plastic, contains rare quartz grains up to 1 mm. In thin sections lenses are observed of silt material and occasionally filamentous remains of prokaryotes, filled with pyrite, emphasizing fuzzy bedding. On clays sandstones overlie sands of Sablinskian suite.

Material composition of clays

Clay minerals have been studied in thin sections by X-ray diffraction using Rietveld method for processing results of quantitative analysis (Fig. 3). Silicate analysis and electron microscopy carried out to determine the chemical composition of clay minerals (Fig. 4).

Vasileostrovskian Formation

Laminaria clays (section "I") are fine dispersed, weakly silted, chlorite-kaolinite-mica with a heterogeneous structure, pelitic and aleuropelitic. Microtexture in some portions is massive or micro-lenticular-wavy. In lenses and micro-layers fine quartz-silt material is accumulated. There is micro-cloggy separateness. The majority is of light olive color. Under crossed Nicols kaolinite is observed in the majority having a low birefringence and interference of gray color. Spheroidal separation of kaolinite occurs (Fig. 4). Among the kaolinite mass a significant amount of mica and illite-smectite is observed. Sometimes mica forms oriented in one direction or lenticular accumulations or microlayers that determine the effect of wavy extinction. In some portions rock is of green color, which is probably due to the admixture of chlorite, possibly associated with the finely divided fragments of chloride biotite.

By particle size distribution silt varieties contain 10-20% of fraction 0.01-0.1 mm. The mineralogical composition of silt and pelitic fractions us polymictic. Among the clastic minerals dimensions of 60-90% are for muscovite, biotite, brown and green, 10% are for quartz and feldspars. The rock consists of siderite, pyrite, magnetite, ilmenite – up to 1%, there are individual grains of tourmaline, zircon. The clay fraction contains up to 15-20% of kaolinite.

Voronkovskian Formation

Silty mudstones are mica-kaolinite (packs of mudstone and siltstone alternation in the bottom part of the section “B-1”), have silty-pelitic and silt structure and horizontal obscure, in some portions disturbed texture (interlayers of silt material about 1-1.5 mm). The argillic interlayers have quartz impurity of 15-25%, a lot of fine micaceous detritus. The composition of silt and sand-silt interlayers: siltstone, quartz, feldspar (no more than 1-3%.). Roundness of clastic material is bad; sorting is bad and average. Large round siderite is characteristic (7-8 in the section), probably by algae (up to 0.7 mm). There is a lot of fine dispersed organic matter in the rock.

In silty clays of the upper part of the section “B-1” (multicolored rocks) coarse siltstone with mica flakes are observed, alternating with layers of fine-grained siltstone and silty clay with ferruginous cement, distributed in layers. Glandular rounded inclusions occur in fine-grained siltstone, possibly formed by organic residues.

Quartz prevails among the debris (25%), modified, layered, green, probably chloride-biotite (up 5%); there are single grains of microcline. Grains of quartz are of average roundness; on the individual grains regeneration rims are observed. Cement is glandular, silty. In some parts it is carbonate. The cement has pretty much elongated crystals of illite-smectite composition, often emphasizing layering. Structure is subidioblastic, granoblastic. Grains are elongated. Texture is layered.

According to the results of X-ray diffraction in multi-colored clays lepidocrocite is found in addition to kaolinite and mica.

Lomonosovskian Formation

Silty clay (sections “K-1” and “K-2”) has kaolinite, chlorite and illite-smectite composition, pelitic structure, layered, oriented parallel to the bedding texture due to interbedded with thin layers of sand and silt material. The silty-sand impurity has quartz, plagioclase grains. Grains are sharp-edged, less half-rounded. Organic matter is fine scattered, oriented parallel to bedding. There are single grains of fine chlorite. The major minerals are dominated by quartz – up to 40%; illite-smectite – up to 25%, green biotite – up to 15%, feldspars -up to 5%. Clay layers consist of illite-smectite 80%, kaolinite – about 10%. In the heavy fraction titaniferous minerals, epidote and zircon are found. The fine portion is

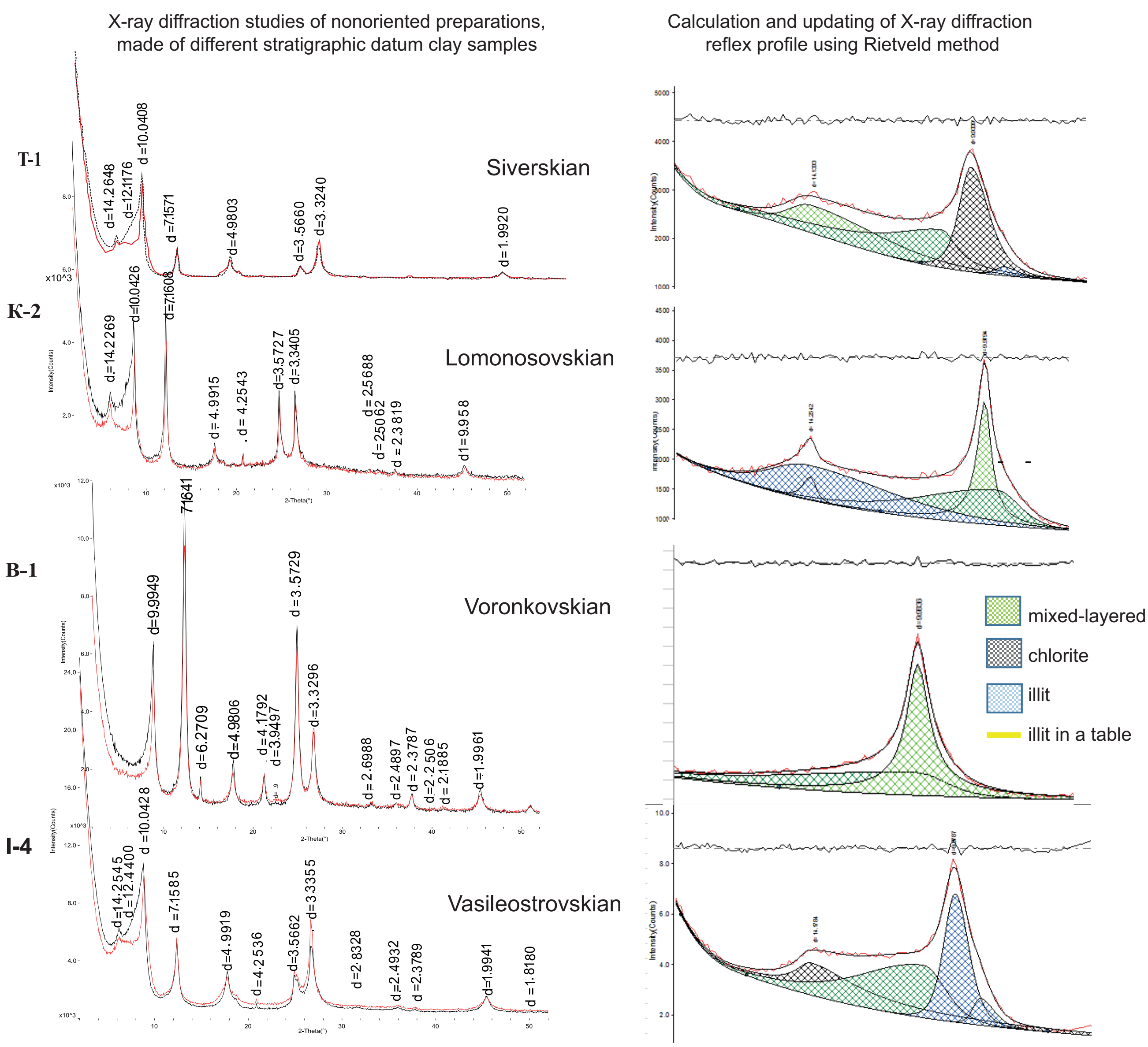
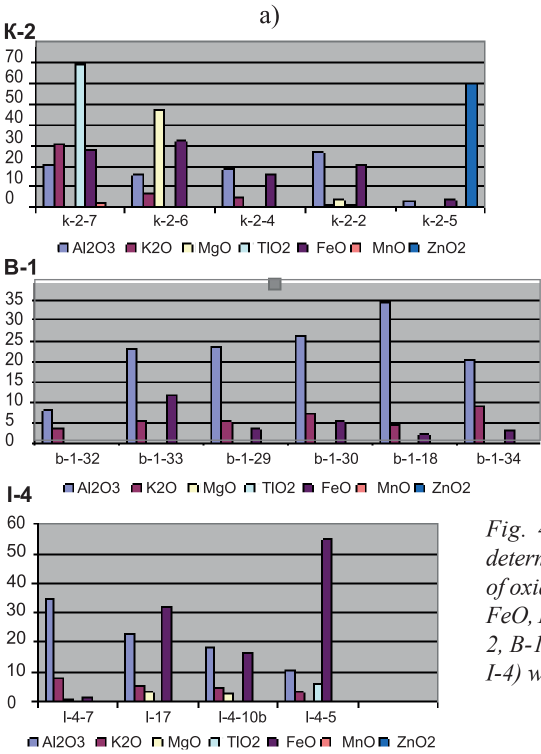


Fig. 3. The mineral composition of clay fraction.

a)



b)

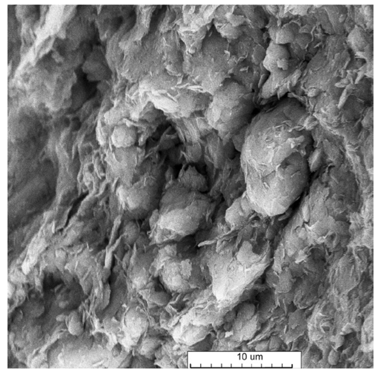


Fig. 4. The chemical composition of clay, determined by electron microscopy: a) diagram of oxides distribution (Al_2O_3, K_2O, MgO, TiO_2, FeO, MnO, ZnO) of examined clay samples (K-2, B-1, I-4); b) microstructure of clay (sample I-4) with spheroidal kaolinite.

represented with hydromicas, glauconite, and, rarely, chlorite, montmorillonite. Sporadically in fine-grained clay mass there are large grains of quartz, glauconite, feldspar, pyrite.

Siverskian Formation

In clays over 80% of particles are attributed to fraction of less than 0.01 mm. More than 50% are mixed-layered formations and chlorite. The fine clays have lenses of silt material with grains of quartz. Kaolinite was identified when conducting diffractometric studies.

As a result of silicate analysis of samples taken from clays and siltstones in Vasileostrovskian, Voronkovskian and Lomonosovskian formations, the chemical composition of deposits is stable.

Diffraction patterns of clay from Vasileostrovskian, Voronkovskian and Lomonosovskian formations have a similar appearance (Fig. 3).

Crystallite thickness decreases down the section (to Vasileostrovskian part of the section). The presence of illite-smectite components and the amount of illite in sediments of Lomonosovskian and Sablinskian formations (sections "K-1", "K-2" and "T-1") are comparable with the composition of Vasileostrovskian deposits (section "I"). In the rocks of the section "K-1" illite is probably redeposited.

The presence of chlorite in the rocks indicates on the difference in sedimentation conditions in Voronkovskian and Vasileostrovskian time. In deposits of the section 'B-1' chlorite is not revealed, and in the section "I" chlorite is more ferruginous (14 and 3,54A°), perhaps indicating the humid conditions of sedimentation. In the sections "K-1" and "T-1" the amount of chlorite increases, which suggests the formation of sediments near the shore in cold climates.

The presence of layers of glauconite and sandstones suggests the formation of silt-clay formation in the conditions of the coastal shallows. According to the potassium-argon method for glauconite (Anderson et al., 2006), the absolute age of Cambrian clay was determined as the 530-590 million years.

These data indicate on the isolation of K-Ar system in a relatively easy metamorphosed mineral, and therefore, long-term stability of the entire clay formation for half a billion years.

The rocks of voronkovskian suite (section "B-1") include illite material, catagenetic kaolinite; there is no smectite, which is typical for sea level fluctuations. In Kotlinskian time the basin was deeper and warmer, possibly with alternating wet and dry periods. The material accumulated at large distances from the source of ablation – in the rocks of the section "I" there is a significant amount of smectite.

Slightly higher clarke contents of Fe – up to 5.56% in clays of voronkovskian suite is probably due to supergene processes.

To restore the paleoclimatic conditions of accumulation of fine-grained sediments, relationships of petrochemical modules were used (Akulynina, 1985).

In relation $A1_2O_3/TiO_2$ in the fine fraction of clay – from 19.76 to 20.11 (<20 unit) and in terms of the index of chemical weathering CIA = $[Al_2O_3/(Al_2O_3 + CaO + Na_2O + K_2O)] \times 100$ from 75.95 to 79.62 (> 70 units) we may assume humid conditions of sediments accumulation under intense chemical weathering on adjacent land in the Vendian and Cambrian time.

Low titanium content and high aluminum content probably characterize open sea conditions. Stable values of Ni/Co ratio (from 0.88 to 3.66) and V/Cr (<2) indicate that the formation of the Vendian and Cambrian clays occurred under oxidizing conditions with good aeration of bottom waters.

At the Cambrian time sedimentary conditions have changed a bit – the basin became open shallow water, as evidenced by the appearance of sand layers with glauconite. Compared with silty rocks, the content of V (115-126) and Cr (80-104) increased slightly in clay.

Conclusions

1. From the combination of lithological features and higher content of iron, formation of Upper Vendian and Lower Cambrian silt-clay deposits occur in the lagoon environment, periodically changing with coastal shallow environment. Kaolinite-smectite -illite clay composition and the presence of fossil prokaryotes in debris, probably indicate on a moderately humid climate and areal active physical weathering on the adjacent land.

2. At the same mineral composition and grain size as well as its physical and mechanical properties the strata do not differ from each other.

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Manuscript received April 13, 2016