Bull. Nov. Comp. Center, Math. Model. in Geoph., 18 (2015), 53–67

On the origin of the Ladoga impact-volcanic structure

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Abstract. In the geo-information and geological studies of the last two years we has accumulated a sufficient number of geophysical, morphological, mineralogical and petrographic materials to refer the Ladoga structure to the category of the "proven" astrobleme. The identification within the Ladoga structure of the volcano-plutonic complex, which is syngenetic to an astrobleme, allows us to classify this formation as a single impact-volcanic structure: Ladoga IVS.

Keywords: impact cosmogenic structures, natural disasters databases, morpho-structural elements, gravity.

1. Introduction

In the author's catalog of impact structures [1] the Ladoga structure ($L =$ 80 km, age ~ 40 thousands years) was classified as a "probable" astrobleme. However, based on the results of the geo-information and geological studies of the last two years, there is the sufficient reason to transfer this structure to the category of the "proven" astrobleme.

The geo-information criteria are that geographically the Ladoga structure is a part of the block of a few ring gravitational perturbations, specific of astroblems. Perturbation of this block is identified on the background of the last isostatic uplift of Fennoscandia, which indicates to their single age.

To geological (morphological, mineralogical and petrographic) criteria of the impact genesis of the Ladoga structure, we can include the following:

- Availability of the crater form and of the base bank;
- Distribution within the impact structure of a coptogenic complex represented by a classical forming set of impact structures — the authigenic and allogenic breccias, suevites, tagamites, and scattered outlets;
- The shock metamorphism in target minerals — diaplect changes, isotropization, and shock cracking;
- Everywhere, at all points of a sampling, the distribution of the marker of an impact event — the high-pressure mineral "moissanite" [2].

A volcano-plutonic syenite complex within the Ladoga structure is represented by extrusive parts of the Ladoga volcanic dome and of the corresponding in composition trachytic ashes of the Pleistocene age, widespread in the Russian Plain.

Under the Pleistocene ashes, the well-dated Upper Paleolithic ancient settlements of the Kostenki–Borshevsky region [3] were buried, that allowed us (in addition to paleoclimatic data) to specify the age of the Ladoga IVS as 38,500 years.

In this paper, we consider the most obvious anomalies (in the geological structure, morphology and rock composition of sedimentary and intrusive complexes) that do not fit into conventional models and are the evidence of the impact origin of the Ladoga structure. We present the new geo-information models of the impact origin of the basin of Lake Ladoga and the main features of the impact metamorphism in the rocks of Ladoga IVS.

2. Physical and geo-information models of formatting the Ladoga structure

According to the impact-volcanic model, the Ladoga basin was formed by the fall of a massive cosmic body (CB), led to forming an explosion crater, to which the deep part of the lake is confined (line 2 in Figure 1). One of the main features of the Ladoga structure is that it includes the volcanic edifice, presented by a series of extrusive domes developed on the periphery of the ruined central uplift, and the caldera of subsidence. This means that the impact of the cosmic body has violated the solidity of the Baltic Shield, which resulted in a large-scale eruption in terms of the size of the caldera. The volcano-plutonic Ladoga complex consists of subvolcanic syenites, formed by the extrusive dome, and of the corresponding composition of the trachytic ashes, widespread in the Russian Plain. A tail of these ashes expands from the eastern Baltic to the Azov Sea. Totally, the Ladoga eruption throws

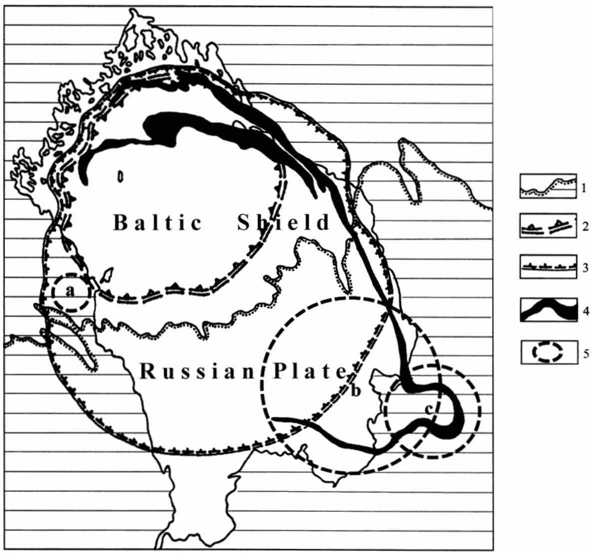

Figure 1. Structural and tectonic scheme of the Ladoga IVS and its surmised accompanying mini-craters: 1 — the boundary between the rocks of the plate cover (the Russian plain) and the crystalline basement (Baltic Shield); 2 — the contour of the explosion crater; 3 — the contour of the subsidence caldera; 4 — the distribution of impact melt formations (tagamites); 5 — the contingent contours of mini-craters

into the atmosphere about 1,500 km^3 of ash, resulting in the huge, about 140 km across, caldera of subsidence, thus forming the southern, shallow part of Lake Ladoga (line 3 in Figure 1). Thus, in the model described, the Ladoga basin is a single syngenetic impact-volcanic structure—Ladoga IVS [4].

The activation reconstruction of the described Ladoga events was performed using the simulator "Earth Impact Effects Program" (Imperial College, 2010) with the following parameters: the CB diameter is 11 km; the density of the CB and target are 3000 and 2750 kg/m^3, respectively; the CB velocity is ~ 17 km/s; the angle to the horizon is $\sim 20°$, etc. Calculations have shown that the parameters proposed and the observed effects of events do not go beyond the calculation model.

A comparison with a similar in size and well-studied Popigai impact structure shows that the main features of the morphology and geological structure of the Ladoga and the Popigai structures are almost identical [5]. For example, in both structures, there are observed outcrops of two subparallel layered bodies of tagamites (the Ladoga tagamites will be discussed below), there are similar radial tectonic faults around the perimeter of the crater, there is no central uplift [4]. The Ladoga layered bodies as well as the Popigai tagamites, come to the surface near the outcrops of crystalline rocks, i.e. metabasites of the Sveko-Karelian complex, and the Salmian array of Lower Riphean granites in the first case, and of intensely granitized gneisses of the Upper-Anabar and Hapchanian Archean series in the second case.

A comparison of characteristic elements of the Popigai, Ladoga and other structures in terms of the gravity data (Figures 2a and 3) also shows evidence of the impact genesis of the Ladoga basin. Although the negative gravity anomaly within the crater Ladoga (the oval A in Figure 2a) has a relatively low intensity, but it looks pretty typical of an impact craters due to its circular shape. From the gravity data, we can also identify a wider ring structures: the oval B (see Figure 2a), constructed according to the orientation of intense negative anomalies, and the oval C, which traces the positive gravity anomaly. The structure contoured by the oval C (see Figure 3a) is expressed both in the relief (see Figure 2b), and in the positive gravity anomalies in all their modifications (see Figure 2a, an inserted picture in Figure 2b, and Figure 3a). Its approximate size is 300 × 200 km. Such an "external" contour in the form of a positive ring anomaly is observed in the transformed gravitational field of the Popigai structure (see Figure 3b). Probably, these formations are due to the paleo-relief formed as a result of the impact and subsequent erosion processes, as the current structure of the Ladoga illustrates. Here, the oval C (see Figure 2a) outlines the depression, including a crater, a subsidence caldera, and lowering the surrounding terrain formed due to denudation and demolition of the material in Lake Ladoga.

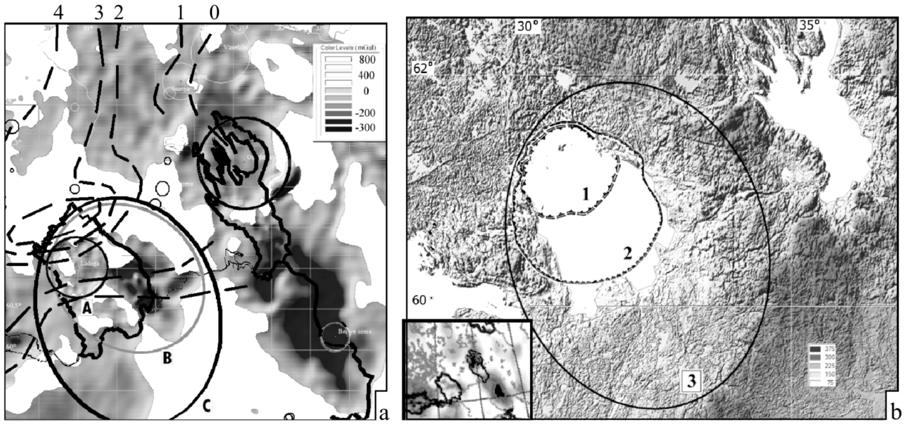

Figure 2. The maps of the area around the Ladoga structures using the GIS ENDDB system [6]: a) the negative gravity anomalies (dashed lines indicate to the contours of the isostatic uplift of Fennoscandia in the postglacial period), in the inserting picture — the gravity anomalies of the Fay reduction (adjusted to the relief); b) the relief: 1 — the boundary of the impact crater (the deep part of the lake), 2 — the boundary of the subsidence caldera, 3 — the external structure, corresponding to a maximum gradient of the relief

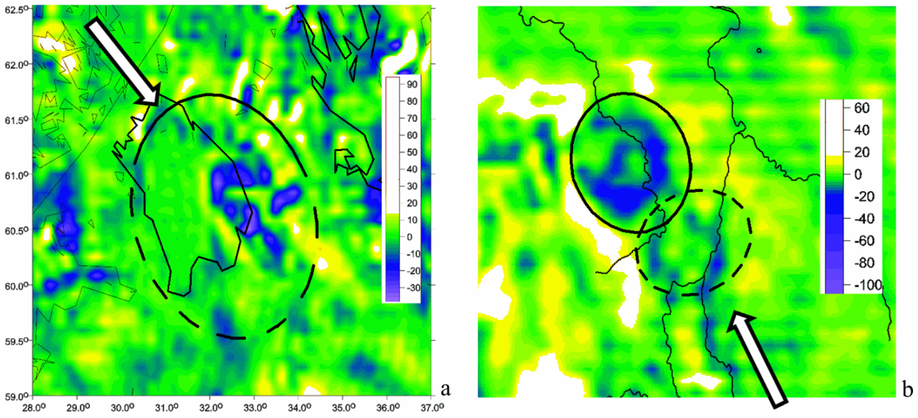

Figure 3. The identified structures using the Tzz anomalies (the second derivative of the gravitational potential tensor) [7], accompanying the astroblemes: a) Ladoga Lake, b) Popogai. The oval corresponds to the border of transition from positive to negative values. The arrows show the probable direction of CB arrival

Comparing the intensive negative anomalies on the maps of Tzz (a gradient component of the gravity field) for Ladoga and Popigai structures, one can note their likeness in size and intensity (see Figure 3). However, in the first case (see Figure 3a) the anomaly is shifted to southeast from the crater center and may show evidence of the size of the structure (corresponding to the oval B in Figure 2a) being significantly larger than that existing in the current relief of the lake (the oval A). This may be caused by the complexity of the Ladoga structure, consisting of many "mini-craters" [8] formed because of decomposition of the impactor onto fragments.

A possible complex structure of an astrobleme assumed according to the whole of the geological material of Ladoga:

1. On the geological map presented in [9] (Figure 5a on page 61), the tagomite layer is traced not only within the deep part of Ladoga Lake, but also far towards south, within "Pash graben" [10];
2. Two overlapped outcrops of the layered bodies of the impact melt intersecting with the Vend and the Cambrian layers show evidence of the existence of two fragmentary overlapping each other "small" astroblemes (mini-craters) (see Figure 1);
3. The rocks stratum drilling in the Pash graben near the Malashata village to SE from Ladoga Lake confirming the existence of two layered bodies similar in composition to the layered bodies in the North part of Ladoga Lake (according to the oral messages of A.V. Kuptsova, S.-Petersburg).

Turning to gravimetric data, let us consider the distribution of possible impact structures [1], contemporaneous with the Ladoga astrobleme. The map shows the radial form of negative gravity anomalies, divergent from one point located outside the map and marked with an arrow (Figure 4a). According to the earlier considered hypothesis about the tail-form of negative gravity anomalies, accompanying astroblemes and tracing the arrival trajectory of CB [1, 6, 11], such a pattern can reflect the process of the CB disintegration in the atmosphere and flying-away its fragments forming a united system of contemporaneous possible structures, in this case: of lakes Ladoga and Onega, craters Valga and Belye Peski, and may also be of unestablished structures Saimaa, Ilmen, Chudsko-Pskovskoye, etc. [1]. Let us note, that earlier we already described different configurations of crater systems formed because of disintegrating the original single CB: ordered groups of craters, chains, concentration ellipses [6, 8]. For example, according to the spatial distribution of crater fields in North America and to the radial distribution of points of the sampling meteorites, drumlines and zones of a high concentration of radioactive potassium (K), the authors [12] concluded that the greatest craters (the bays of Baffin, Amundsen, Hudson and Michi-

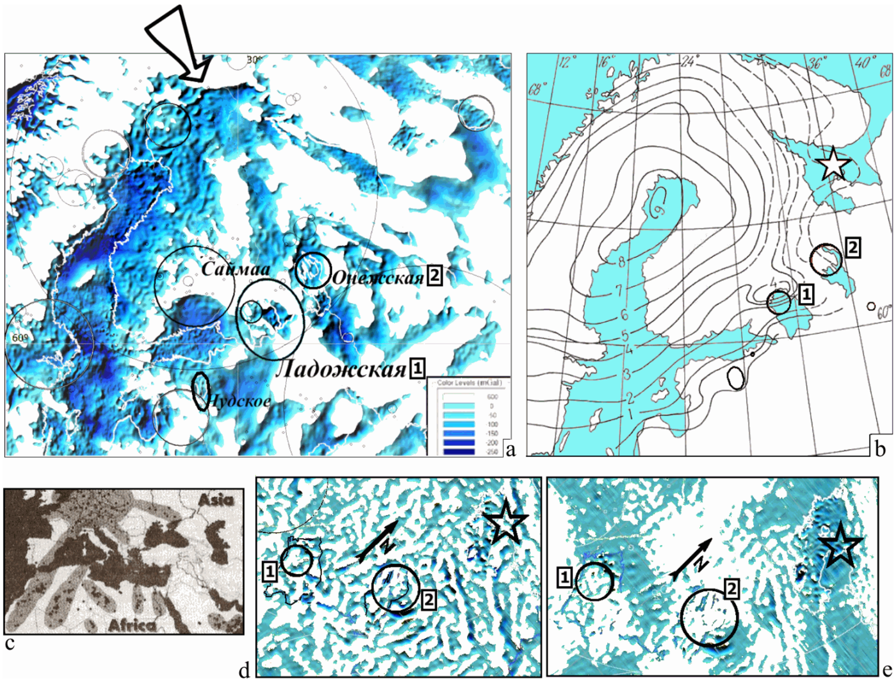

Figure 4. Geoinformation data around Ladoga Lake: a) the traces of negative gravity anomalies (constructed by means of the ENDDB GIS-system [6]) apparently combining possible impact craters into the united system; b) a map of the isostatic uplift of Fennoscandia in Postglacial period (Holocene); c) radial distribution (similar to a) of 3411 findings European, African and Near-Eastern meteorites with the center in the North Europe (according to the Museum of Nature History, London [12]); d–e) the Onega, Ladoga, and Onezhskaya Guba structures (from left to right) on the ENDDB maps of the gravity field transformation by means of the Andreev-Griffin method: $R = 10$ km (d) and $R = 5$ km (e)

gan), as well as numerous Carolina bays [1] are formed of the fragments of a single CB.

The common origin of Ladoga, Onega and other smaller structures, estimated in the region of Chudskoye Lake, is presumably confirmed by a notable disturbance on almost a smooth background of the isostatic restoration of Fennoscandia in Holocene (see Figure 4b, SE part). The correlation of reliable and presumed impacts with disturbances is quite obvious here and allows one to draw a conclusion about the impact nature of gravity anomalies (see Figure 4a). This is because in the isostatic field, most likely, there is a summation of two kinds of restoring: postimpact-volcanic and glacial. The emptiness, appearing in the bowels of the earth after the impact and the subsequent eruption, results in the gravitational settling of its roof (forming the caldera of subsidence), and the subsequent “healing” of the depression funnel in the asthenosphere resulting in the isostatic uplift, abnormal to the total isostatic recovery of Fennoscandia (see Figure 4b). Comparison of these anomalies with gravimetric data reveals not only the known astroblemes [1], but also the potential ones. For example, the disturbance marked as "asterisk" (see Figure 4b) in the isostatic field of the Onezhskaya Guba structure is shown (along with the Ladoga and Onega anomalies) in local disturbances of the transformed gravitational field with small averaging radii (see Figures 4d–e).

The similarity of some features of the geological composition of Ladoga and Onega, and the general features of the morphology of the Ladoga and Onega basins, also, supports the hypothesis of a common genesis of the Ladoga–Onega group of craters. In particular, this is the presence in the Onega reservoir of layered bodies of quartz gabbro-dolerites morphologically and compositionally identical to the Valaam sill of gabbro-dolerites (including the aplite-granophyric lodes and micro-pegmatites) as well as the composition of the Onega Lake graben filled with sediments compositionally similar to the Ladoga impactites (to be discussed in the last Section), and a contrasting relief of the Onega basin.

According to the gravimetric data, we can also note the smaller "satellite" negative anomalies accompanying the Popigai, Ladoga and Onega astroblemes (see Figures 2a and 3). Their possible explanation is that the major fall was accompanied by that of the numerous fragments of a cosmic body (bodies). Practically all the existing geological material about Ladoga, listed above, supports this. For example, the two coincident semirings of the layered body outputs of the impact-melted solids, intersecting the Vendian and Cembrian strata, here indicate to the two partially overlapping "satellite" astroblemes (b and c in Figure 1). Thus, it can be concluded that there were two overlapping satellite astroblemes within "Pash Graben".

3. Morphostructural elements, confirming the impact origin of the Ladoga structure

The apparent anomalies of the Ladoga Lake basin are its morphology: the depths several times higher than the depth of the Gulf of Finland, steep slopes, the extensive manifestation of the current tectonics [14]. These anomalies, as well as the absence of the loose deposits at the bottom of Ladoga as early as the Upper Pleistocene age, are clearly not due to the ancient (Riphean) age of rocks that are controlled in the Ladoga basin in its deep part. This does not find an explanation in any of existing models of Ladoga origin: the tectonic one, defining Ladoga as the Riphean Graben basin [10], the ice plowing one (the lateral chutes-troughs as a result of the ice exaration) [14], and the mixed one (the tectonic origin of a basin transformed by the Quaternary glaciers) [13]. In glaciological models, in the first place, there is no explanation of the contrast intensity of the basin against the background, namely, of the current glacial relief of the northwestern part of the Russian plain.

A series of Stratigraphic Units revealed within the Ladoga basin are exclusive on this territory only and nowhere else. To them, along with the Upper-Riphean and Lower-Vendian deposits, one can refer the Medium-Riphean sediments of the Ladoga deep part. A nearly complete agreement of the material composition and the absolute age of the Medium-Riphean sediments with the composition and age of the Redkino Upper-Vendian horizon [10] shows evidence of distinction of the former as a separated unit not due to stratigraphic considerations (their position in the stratigraphic cross-section), but due to their spatial position. All of these deposits, together with a volcano-plutonic complex, entering their structure [10], fit well to the impact-volcanic model and may be a part of the coptogenic formations of the Ladoga IVS, i.e., of allogeneic breccia formed of the lower horizons of the plate cover, coptoclastites (rocks of the Volyn series according to the map [13]), tagamites (a volcanic complex ibid [13]). Mixing the clastic and melted materials of the impact is, likely, to have formed the coptogenic tuffs of the Medium-Riphean strata described in [10].

Another anomaly of the Ladoga basin strata is “stratigraphic paradox” that can be seen in Figure 5b. Younger rocks of the Redkino horizon, stretching as a wide arc from west to east along the southern section of the deep part of Lake Ladoga, in its northern part lie under the elder Medium-Riphean deposits and proposed deposits of the Volyn series. Despite the fact that the map shows the classic thrust, there is no explanation from the standard point. The classical impact model allows us to interpret it as the base bank, covered with a layer of distant outlets.

The composition of rocks in the Valaam sill is completely unique (see Figure 5), being component of the internal island arc in the deep part of Ladoga Lake. It ranges from the basic gabbro-dolerite to syenite and sub-alkalic high-potassium granite within a single magmatic formation according to the authors of the petro-genesis models. For example, a bulk of research [14] deals with the development and justification of the petrogenetic model of the bimodal magmatism (the mantle basaltic and the crust granitic) of the Ladoga Sill, to which the proposed impact-volcanic model does not contradict in terms of description, but offers a different interpretation of their genesis. According to the impact-volcanic model, the complex composition of the Valaam sill is due to the mixing in the domed structures of impact-melted rocks of the target with an alkaline magma coming from the source of eruption, caused by the collapse of a massive cosmic body. This model without contradiction explains almost all the observed anomalies in the material composition of this unique geological formation, including the above-discussed domed character of constructing syenite structures that are commonly observed in the layered body of the sill.

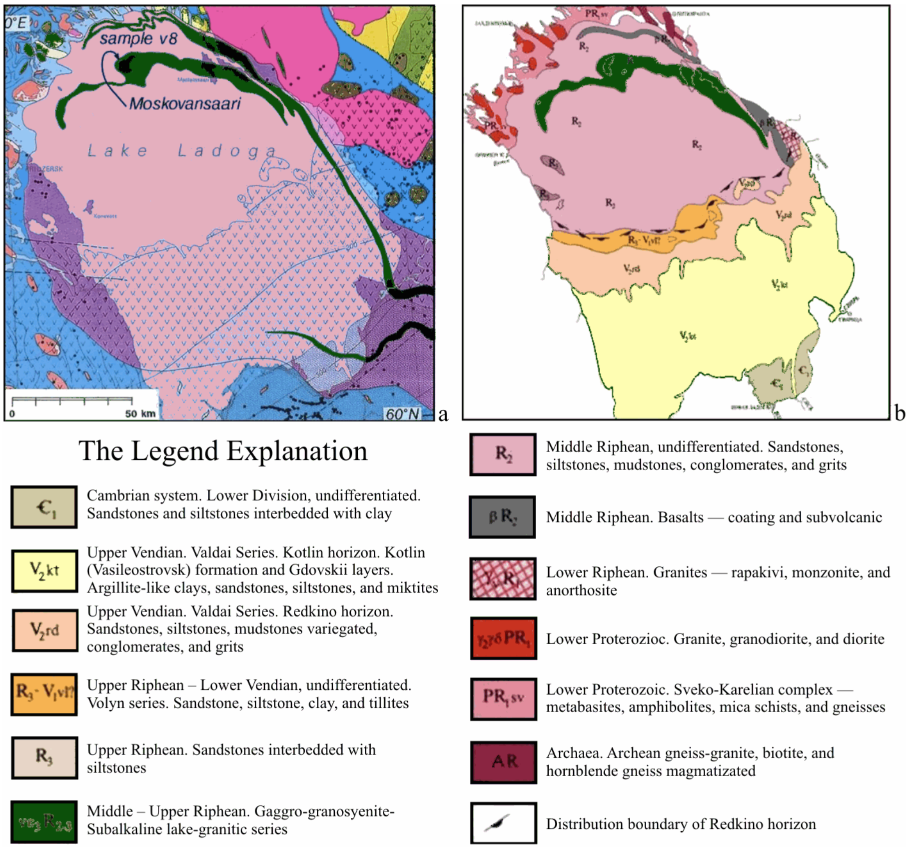

Figure 5. Geological map of Lake Ladoga: a) according to [9], where the scheme is presented without legend: the “stratial” intrusion of “diabase” of the Valaam sill, shown in black, intersects the strata of different ages to the south of Lake Ladoga; b) according to [13], the black dotted line marks the distribution of rocks of Redkino horizon (the Upper Vendian) under the elder sediments of the Middle and the Upper Riphean — Lower Vendian

Thus, the structural-tectonic constructions, based on the conventional view of the Lake Ladoga geology, the petrological model of the genesis of strata composing the deep part of the Ladoga basin, their material composition, stratigraphy and structure of a volcano-plutonic complex in principle do not contradict the proposed impact-volcanic model, and in some cases directly confirm it by apparent anomalies in the geological structure.

4. About the age of the Ladoga astrobleme

As was already mentioned in the previous section, the young age of the Ladoga basin, primarily is evidenced by its contrasting relief, and the absence on its bottom of unconsolidated sediments being older than the Upper

Pleistocene. The oldest sediments of Ladoga presented by glacial-lacustrine bended clays and moraines of the Pleistocene age, overlain by thin Holocene sands, silts and clays [13]. Thus, the age of the basin of Lake Ladoga is likely to coincide with the age of the Valdai glacial strata. Consequently, such an age should have both volcanic rocks of Ladoga eruption and coptogenic complex of the Ladoga astrobleme.

The volume of the eruptive material ejected into the atmosphere by the volcano can be assessed in accord with the created subsidence caldera, and approximately equal to the volume of the Lake: 838 km^3. If we take into account the fact that the weight of the ash is more than twice less than the specific weight of the original rocks, then the eruption ashes are widely spread over the territory of the Russian plain. In their original form, they are stored in the Southern Russian plain as the loess-like sediments of the villages of Kostyonki and Oleksandrivka–Donskaya (the river Duvanka) in the Voronezh region, which have a single eolian origin with layers of ash [15], as well as in the Dnieper–Donetsk interfluve (the map of Quaternary deposits, sheet 11, 1971). These Upper Pleistocene ashes are well studied [16–18] and reliably dated due to the fact that their loss destroyed the widely known Upper Paleolithic stands of the Kostyonko–Borschevsky region which in the past decade actively studied by Russian and foreign archaeologists. A comparison of the chemical composition of the Voronezh River, Ladoga Lake and the volcano ashes has shown their full identity both in average values and within their changes [15]. The age of the ash-covered stands is about 40 thousand years [17].

The loess-like rocks are the central part of the column between two layers of the humified thick, i.e., of ancient soils [16]. Such a situation means that the eruption and, accordingly, the fall of the cosmic body have occurred in one of the peaks of the Valdai glaciation, because, according to the conventional point of view, loess and loess-like rocks are formed in the glacial era in the periglacial zone. The most significant part of ashes of near and middle zones fell on the ice of the Valdai glaciation and on the near-glacial area. Most of these zones is within the Volga River system. Ashes got into the Volga runoff area and with the end of the glaciation was carried away into the Caspian Sea. According to the description of the sediments of the Caspian Sea [19], contemporaneous to the impact event, the ashes were converted by the weathering processes to the so-called "chocolate" clays of the Lower-Khvalynsk Suite of the Upper Pleistocene deposits in the northern part of the Caspian basin. The Lower-Khvalynsk Suite was formed during the Upper Pleistocene maximum transgression of the Caspian Sea. Its age varies between 40–70 thousand years [19]. The top limit of dating corresponds to the age of chocolate clays, located at the top of the column of Lower-Khvalynsk deposits. The age that is more precise can be determined taking into account the paleoclimatic data [4], since the age of 40 thousand years well correlates with the peak of the Leyastsiem glaciation that on the scale of Climate correlations is marked as 38,500 years [15].

Perhaps it was this event which put our ancestors on the brink of survival and was the reason for their transition to a new stage of development, reflected in the epics of ancient Slavs: "As there were people in the rank animal… As there was descended from the heights as the hammer stone, As from fight this the sky was dark, As there was descended into the forest the fire singed… As animal were — as human steel".

5. On a possible direction of the Ladoga cosmic body arrival

The north-northwest direction of the CB arrival is confirmed by the asymmetry of the structural-tectonic basin of Lake Ladoga (see Figure 2b), as well as of configuration of the negative gravitational anomalies (see Figure 4a) of the Ladoga-Onega structure system.

Such a direction is indicated by the positions of the described above classical thrust (typical of the front of the impact craters [20]) along the southern section of the deep part of Lake Ladoga, as well as by the spatial position of the southern explosive breccia (Ladoga suite [10]) and of the ashes of Ladoga eruption [15].

Contours 1–3 built in Figure 2b show the structural-tectonic asymmetry of Ladoga IVS, which is at the center of the explosion crater (the deep part of Lake Ladoga) being not matched to the center of the subsidence caldera (the shallow part). The latter means that the source of magmatic material was at some distance horizontally from the crash point of a cosmic body. With a strictly vertical fall, these centers would coincide. Most likely, along an imaginary line connecting these centers, the impact was directed compromising the integrity of the lithosphere. The azimuth of this line is $\sim 150°$.

This direction is indirectly confirmed by a gradual depth increase towards SE of the roof of a crystalline basement (from 1,000 to 1,500 m) [13], which may show evidence of an inclined position of the magma supply channel that has occurred against the inclined impact ($\sim 20°$ to the surface). With such a direction to the focus of deep tectonics of the Ladoga IVS, there is a correlation of the south-easterly dipping folds of the Valaam dome [15] detected near Valaam Island [14].

6. Elements of impact metamorphism in rocks of Ladoga IVS

Sufficient elements of an impact are the following: the presence of rocks produced from the impact melt, namely, tagamites; the presence of shaking cones; the diaplect changes (cracks, planar elements, shock-thermal decomposition) in the minerals of the target; the presence of high-pressure minerals in the rocks. Finding any of these signs indicates to the presence of an impact. In the Ladoga structure, all these elements are found.

Samples with signs of the impact metamorphism were selected in different years, at several points of the western shore of Lake Ladoga and in the southern Ladoga. Papers [2, 4, 21] summarize the results of a studying these samples in transmission; give the data of microprobe and X-ray analysis performed.

A common feature that unites the samples at all sampling points is the presence of shock structures of microscopic order. Their dimension varies from ~ 0.05 to ~ 0.3 mm. Their formation is accompanied by the formation of concentric and, sometimes, planar fractures, and by the shock melting of mineral grains in the target (Figure 6). In some samples, microstructures are being in contact and partially overlapping, forming the "microfields" subject to "microprojectile".

Typically, at the centers of the shock microstructures as a thin fraction (less than 0.02 mm), which sometimes is in the form of individual grains of 0.1–0.16 mm (Figures 6b, 7b) the moissanite is present (Figure 7), in which a high relief, a sharp shagreen surface and interference of pearl color are observed. Sometimes, the moissanite microstructures are present in significant quantities.

All such microstructures are found near the surface of the samples. A high-pressure mineral moissanite, which, along with diaplect changes and deformation structures, is a reliable sign of an impact event. It was found on Lake Ladoga and its surroundings at all sampling points: from the village of Shapki, located 30 km south of Ladoga Lake, to the town of Priozersk in the northern part of Lake Ladoga. The distance between the outermost points is 163 km, indicating to a large scale of disaster, even without taking into account an assumed impact in the area of Onega Lake [4].

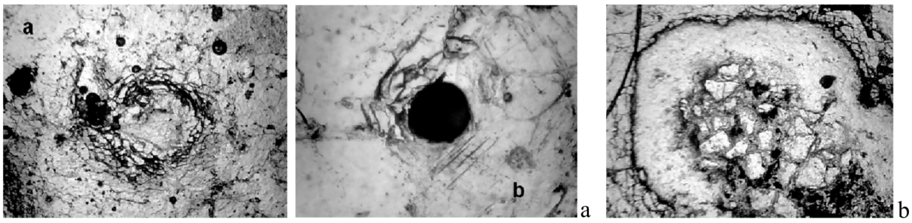

Figure 6. Shock microstructures: a) in a fragment of sandstone in allogeneic breccia (Vladimirov Cape. Micro-section No. 1. Plane-polarized light. The field width of 0.9 mm); b) in quartz grains of the Cambrian sandstone (Micro-section No. 6. The field width of 0.28 mm. The concentric fractures, crushing the target minerals, diaplect glasses)

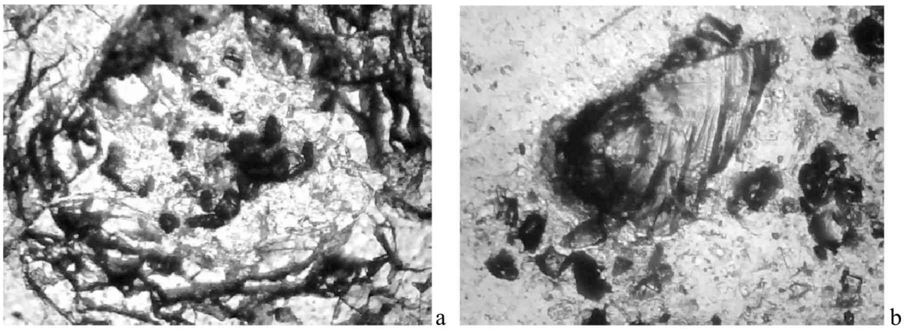

Figure 7. Shock microstructures of moissanite: a) in sandstone (Vladimirov Cape. Micro-section No. 1. The field width of 0.28 mm. The dark angular grains at the center are the moissanite); b) the large grains in the microstructure of moissanite (Cambrian sandstones. Micro-section No. 13. The field width of 0.28 mm)

7. Conclusion

As a result of the above-considered, one can make a confident conclusion: the impact hypothesis of the Ladoga structure formation found its confirmation by the physical models, geomorphological data and mineralogical studies. As an additional argument in the dispute with supporters of concept of the endogenous origin of the Ladoga structure let us quote Alexander Ottovich Schmidt, a leading researcher of VSEGEI, ten years ago was said: "To the important discovery one should refer ... the proof of the Upper-Pleistocene (not Riphean as was previously thought) origin of the Ladoga Lake resulted from the "Ladoga astrobleme" impact. The arguments of the presence of "Riphean Graben-Syncline" allegedly inherited by the Lake should be allowed without proof. The confirmation of the presence of the local volcanic center in the area is an unconditional contribution ... to the geology of the astrobleme".

There are still many questions creating in the analysis of geo-information models, especially, when comparing them with geological data. In particular, it should be noted that the geological knowledge of the Ladoga and the Onega areas is insufficient for unambiguous interpretation of geospatial data in terms of mapping the "satellite" astroblemes, although their relationship with the "satellite" anomalies of the gravitational field, at the first glance, seems obvious.

Discovering the shock microstructures in rocks of the Ladoga IVS not only confirms its impact genesis but, also, reveals that not all the impact processes are already known, and researchers of Ladoga may expect many new discoveries.

Acknowledgements. The authors are grateful to Vladimir Fedorovich Sapega (the Laboratory of Mineralogical Analysis Methods of FGUP "VSEGEI") and Aleksey Ivanovich Chernyshov (the Department of Petrography of Tomsk State University) who have fulfilled microstructural analysis of samples of the Ladoga structure.

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