Late Holocene malacofauna-based paleoenvironmental reconstruction for the Bazaikha River and Tartat River valleys (Krasnoyark Depression, Central Siberia)

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Abstract. The results of malacofauna-based palaeoenvironment reconstructions for the Late Holocene in the valleys of Bazaikha and Tartat rivers (Krasnoyark depression) are presented. Palynological analyses of the flood-plain deposits and radiocarbon dating complemented malacofaunal analysis. Biodiversity of malacofauna is represented by 7 freshwater species and 15 land species. Species belonging to the Valloniidae Morse, 1864 and Lymnaeidae Rafinesque, 1815 families are dominant in the fossil assemblages. The finding of Gastrocopta theeli shell in the Late Holocene deposits of the Bazaikha section is the first one in the territory of Krasnoyarsk depression. This finding supports the relic, spotted character of the geographic range of this species. Emploting malacofauna proxies and the Eleneva Cave reference section palynological record enabled reconstructing Late Holocene palaeoenvironmental conditions in the area. Malacofauna in the valleys of Bazaikha and Tartat rivers developed under the conditions of gradual increase in heat availability and decreasing annual precipitation and warm-period precipitation during the last 2500 years. A reduction of malacofauna diversity 950 years ago was caused by a change in the precipitation regime.

1. Introduction

Among many methods of paleogeographic studies, the malacofaunal analysis provides unique data on changes of mollusks’ environment. The method applicability in Holocene paleoclimate and paleolandscape reconstructions are related to the broad distribution of malacofauna and a good degree of preservation of shells in deposits of different geneses [1]. Precipitation and sedimentation conditions, temperature regime, and character of vegetation evolution can be deduced utilizing a close connection between the mollusk habitat conditions and the broader environment. Furthermore past landscapes and timeline of their successions can be reconstructed. The malacofauna studies are widespread in the world, whereas in Russia they have been limited to the European part of Russia, the Urals, and East Siberia [2-16].

Attention to the Holocene mollusk shells from the Krasnoyarsk depression for paleogeographic analysis has been drawn relatively recently. While studying lacustrine, swamp, and alluvial deposits of the Krasnoyarsk depression, A. F. Yamskikh and G. Yu. Yamskikh revealed several locations with abundant mollusk shells [17, 18]. The data on species composition of the regional malacofauna and its Pleistocene and Holocene distribution is scarce and is available mostly at archeological monument locations [19-23].
Late Holocene mollusk shells were recovered from flood-plain deposits of valleys of the Bazaikha and Tartat rivers. These rivers are the Yenisei River tributaries, both located within the limits of the Krasnoyarsk depression (figure 1). Indicative properties of malacoфаuna and results of palynological study of the Eleneva Cave stratotypical reference section [24] were employed to deduce the palaeoenvironmental conditions over the last 2500 years in the Krasnoyarsk depression.

Figure 1. Locations of the studied sections (https://www.google.com/earth/).

2. Regional setting
The study area is located within the limits of the Krasnoyarsk depression, at the junction of the East Sayan, West Siberian Plain, and Central Siberian Plateau [17, 18, 25]. The Krasnoyarsk depression is of piedmont type, according to the N. V. Fadeeva general classification of the depressions [26]. The geological structure of the area is characterized by the Devonian and Carboniferous volcanogenic and variegated terrigenous deposits, flat dip Jurassic and Mesozo-Cenozoic deposits, superimposed by Quaternary deposits. Clay loams and sandy loams are the most widespread among the latter [27]. The complex character of topography in the study area is due to the combination of heterogeneous tectonic structures of different ages (Altai–Sayan Paleozoic folded zone, West Siberian young plate, and Precambrian Siberian Platform) [25].

In terms of geomorphology of the Krasnoyarsk depression, the topographic stages related to the terraces of the Yenisei River and interfluves are particularly noteworthy. A. F. Yamskikh [28] distinguished nine terraces within the limits of the depression. In terms of structural and morphological peculiarities, these terraces were grouped to form three complexes: the high-level (including terraces at 120–135 (150), 90–120, and 60–80 m), the medium-level (35–55 m), and the low-level (24–30, 15–18, 10–14, and 7–10 m). The date for onset of the flood-plain formation is 6–4 ka BP. [17]. The terraces and the flood-plain are composed mainly of alluvium, consisting of clays, gravels, and pebblestones.

The climate of the area is extremely continental, characterized by the harsh and long winter, short and rather hot summer. Quickly changing seasons and considerable temperature-change amplitudes are typical here [29]. The river network belongs to the basin of the Yenisei River middle stream. The soils are represented by the common and leached chernozems, the podzols, the gray forest and swamp soils, the flood-plain soils, the meadow soils, and the meadow chernozems. The vegetation of the area is influenced by the closeness of the forest-steppe and the mountain taiga natural complex boundaries. It is represented by the forest, steppe, grassland, shrub, and swamp assemblages [30–32].
3. Material and methods

The Late Holocene palaeoenvironmental conditions were studied based on the results of the malacofaunal and palynological analyses. The radiocarbon dating method provided the timeline.

3.1. Site characteristics and sampling

The paleontological material was collected from clays, clay loams, and sandy loams of the flood-plains of the Bazaikha and Tartat rivers (figure 1). The Bazaikha section (0.8-m thick) was excavated in the near-mouth part on the left bank of Bazaikha River, at the distance of 4.8 km from its influx to the Yenisei River (southwestern edge of the city of Krasnoyarsk; absolute altitude is 155 m). The Tartat section is located in the Tartat River valley, 5 km to the northeast of Sosnovoborsk (146 m a.s.l.). The Tartat River of about 33 km long crosses the massif of the same name. The flood plain relative height is between 0.5 to 1.6 m. The section of 1.54 m high was studied in the flood plain outcrop in the Tartat River valley.

Sampling and shell collection was performed using standard methods [1, 33-35]. To carry out detailed reconstructions, samples of 8 dm³ in volume were collected from bottom to top with a 5-cm interval, taking into account the boundaries between layers. Mollusk shells were extracted by washing in 0.5–0.25 mm sieves. Cleaning of shells and taxa determination were performed under a binocular microscope. Mollusks were determined from literature descriptions and fossil shell collections by A. F. San'ko [36] and N. V. Lebedeva [37].

Mollusk species found in flood-plain deposits of the Krasnoyarsk depression were placed into ecological groups based on their environmental conditions. The classification proposed in [5, 11, 38, 39] was employed. Eleven ecological groups of mollusks were distinguished. Among land malacofauna, representatives of shaded and partially shaded weakly humid landscapes (Fb) were distinguished, as well as species inhabiting forests and shrubs on moderately humid soils (Fm), those of open unforested landscapes (So), of humid shaded rocks (Fr), mesophilic mesophilic species of open or shaded biotopes (MM), and mollusks typical of highly humid biotopes, or swamp biotopes, or temporary wetlands (WD). Among freshwater malacofauna, four ecological groups were distinguished based on such criteria as water permanence of a water object, trophicity, and stream character: wetland mollusks inhabiting shallow and ephemeral water objects (Wd), mollusks from ephemeral, intensively overgrowing and silted water objects (Wl), mollusks inhabiting lakes and other permanent water objects or living in lagging waters (WL), euriecolical freshwater mollusks inhabiting both river and lakes, in both running and dead waters (We).

Variations in mollusk shell quantities observed in the deposits (figures 3 and 5) are documented using Microsoft Excel, C2 software. The change of paleomalacofaunal assemblages is given based on percentages of mollusks from various ecological groups (figures 4 and 6).

We employed the palynological data from the Eleneva Cave stratotypical section [24] for the quantitative characteristics of paleoclimate and landscape elements. The section is located at the left bank of Yenisei River, at the mouth of Karaul'naya River, west of Krasnoyarsk. Standard techniques were employed for the preparation of specimens for palynological analysis [40]. The regression equations [18] were used to reconstruct paleoclimate parameters.

3.2. Radiocarbon dating

Radiocarbon dating of the specimens from the Bazaikha and Tartat sections was carried out at the Laboratory for Archeological Technology (Institute of the Material Culture History of the Russian Academy of Sciences, St. Petersburg), and at the Laboratory of Isotopic Research (Geology Center of Common Use, Department of Geology and Geocology, Faculty of Geography, Herzen Russian State Pedagogical University, St. Petersburg). Radiocarbon ages were calibrated (table 1) using the CalPal software [41]. Determination of ages of deposits from the Eleneva Cave section was made at the Laboratory for Cenozoic Geology and Paleoclimatology (Sobolev Institute of Geology and Mineralogy, Siberian Branch of the Russian Academy of Sciences, Novosibirsk).
4. Results
The time limits of Holocene climatic phases were identified based on the radiocarbon dating of the deposits from the studied sections (table 1, figure 2), as well as the paleobotanic data [18, 24].

| Section and sampling depth from the surface (cm) | Radiocarbon$^{14}$C age | Lab number | Calibrated age (cal yr BP) |
|-----------------------------------------------|-------------------------|-------------|---------------------------|
| Bazaikha 0.1-0.15                             | 1498±50                 | SPb-1814    | 1410±60                   |
| Bazaikha 0.3-0.35                             | 1844±50                 | SPb-1815    | 1790±60                   |
| Bazaikha 0.60-0.65                            | 1884±50                 | SPb-1816    | 1820±60                   |
| Tartat 0.24-0.29                              | 2320±40                 | Le-11218    | 2310±50                   |

4.1. The malacofauna of the Bazaikha section
The taxonomy of malacofauna collected from the clay and clay loams of the Bazaikha section in the intervals of 0.8–0.3 and 0.15–0.05 m depth was determined. A total of 309 fossil mollusk shells were examined. The determined taxonomy is represented by 7 freshwater and 14 land species. Valloniidae Morse, 1864 and Lymnaeidae Rafinesque, 1815 families dominate among the fossil assemblages (figure 3).
Figure 3. Frequency diagram for malacofauna of the Bazaikha section.

During 2400 – 1650 cal yr BP, the mollusks of open landscapes dominated (figure 4). At 0.8–0.75 m depth, the fauna is represented by *Vallonia pulchella* species corresponding to the unforested biotopes (Müller, 1774). The next stage was characterized by inclusion of mesophilic *Perpolita hammonis* (Strom, 1765) species typical of open or shaded landscapes. Beginning from 0.7 m depth, faunal assemblages demonstrate an increase in the proportion of freshwater and land hydrophilic mollusks, pointing to a gradual precipitation increase. *Lymnaea peregra* (Müller, 1774) and *Gyraulus rossmaessleri* (Auerswald, 1851) referring to ephemeral water objects, as well as *Armiger crista* (Linnaeus, 1758) species typical of permanent water bodies, found at 0.65–0.7 m indicate that a shallow and well-heated water body existed in the respective time. The subsequent assemblage is characterized by the absence of freshwater species, by the inclusion of *Cochlicopa lubrica* (Müller, 1774), *Succinella oblonga* (Draparnaud, 1801) that are typical of humid biotopes with various degrees of shading, and *Succinea putris* (Linnaeus, 1758) and *Carychium minimum* Müller, 1774 that correspond to swamps and temporary wetlands.

Figure 4. Percentages of ecological groups in malacofaunal associations of the Bazaikha section.

The amounts of both land and freshwater mollusk shells gradually grow in the 0.45–0.6 m depth interval, indicating the increase in water availability. The most abundant in this assemblage are
mollusks of unforested biotopes *Vallonia pulchella* (Müller, 1774), *Vallonia costata* (Müller, 1774), and *Pupilla muscorum* (Linnaeus, 1758), which quantitatively make up 40% of the total number of shells in the assemblage. Among mesophilic mollusks, four land species are present: *Cochlicopa lubrica* (Müller, 1774), *Vertigo alpestris* Alder, 1838, *Perpolita hammonis* (Strom, 1765), and *Euconulus fulva* (Müller, 1774). The taxonomy of mollusks inhabiting humid biotopes is constant until 0.45 m depth from the flood-plain surface. Freshwater malacofauna is represented by species of small periodically overgrowing water objects. The increased number of *Lymnaea peregra* (Müller, 1774) and *Gyraulus rossmaessleri* (Auerswald, 1851) shells, as well as the general taxonomy of malacoferal assemblage, suggest an increase in precipitation. The fractions of species inhabiting open biotopes and hydrophilic mollusks decrease, while those of wetland species and mollusks inhabiting small and ephemeral water objects increase in the depth interval of 0.4–0.45 m. The *Vertigo alpestris* Alder, 1838 species, which inhabits predominantly forests or humid shaded rocks, appears in the assemblage.

At 0.35–0.4 m depth, thanatocenosis is characterized by the greatest taxonomic diversity. The most completely represented is the group of mollusks inhabiting small overgrowing water objects: *Lymnaea truncatula* (Müller, 1774), *Lymnaea peregra* (Müller, 1774), *Lymnaea sp.*., and *Gyraulus rossmaessleri* (Auerswald, 1851). Among freshwater taxa, the species of permanent water objects appear, i.e. *Gyraulus albus* (Müller, 1774) and *Gyraulus laevis* (Alder, 1838). The general composition of mesophilic species group, with the inclusion of *Punctum pygmaeum* (Draparnaud, 1801), remains constant. Mollusks of open biotopes are presented by only two species: *Vallonia pulchella* (Müller, 1774) and *Vallonia costata* (Müller, 1774). However, in terms of quantity, their shells are dominating. Also, the *Gastrocopta theeli* (Westerlund, 1877) and *Fruticicola schrenckii* (Middendorff, 1851) species, indicating shaded and partially shaded biotopes, appear here. At 0.3–0.35 m depth, such species as *Succinea putris* (Linnaeus, 1758), *Lymnaea peregra* (Müller, 1774), and *Pisidium casertanum* (Poli, 1791) form the assemblage characteristic of humid biotopes of periodic wetlands. At 1800 cal yr BP humidification of the territory increased [24], as indicated by a gradual increase in amounts of freshwater or hydrophilic species in the thanatocenosis. The representatives of both open biotopes (*Vallonia pulchella* (Müller, 1774), *Vallonia costata* (Müller, 1774), *Vallonia sp.*) and ephemeral water objects (*Lymnaea truncatula* (Müller, 1774)) are present in the assemblages at ca. 1400 cal yr BP.

4.2. The malacofauna of the Tartat section

In the flood-plain outcrop at the Tartat River, the remained malacofauna (46 shells) were recovered from the surface down to 0.24 m depth. Holocene malacofauna of this section is characterized by reduced diversity and a smaller amount of mollusk shells. The land species dominate (figure 5).
It was determined based on the botanic studies of the organogenic deposits from the Tartat swamp area, that peat accumulation in the studied area began in the middle Holocene as a result of shallowing and overgrowing of a water object [18]. Peat volume does not contain mollusk shells.

The malacofauna of the study area began to form later (2300 cal yr BP) under a warm and moderately humid climate [24]. At 0.24–0.17 m depth, thanatocenosis includes one mollusk species inhabiting shallow and ephemeral water objects, namely, *Lymnaea peregra* (Müller, 1774). Land mollusks are represented by single ones typical of unforested landscapes, and also by mesophilic and hydrophilic species: *Vallonia pulchella* (Müller, 1774), *Cochlicopa lubrica* (Müller, 1774), *Vertigo* sp, *Succinea putris* (Linnaeus, 1758), *Vertigo antivertigo* (Draparnand, 1801), and *Euconulus fulva* (Müller, 1774).

At 0.17–0.1 m depth, the taxonomy of the assemblage changes (figure 5) toward the complete disappearance of freshwater species, while land species include mesophilic *Punctum pygmaeum* (Draparnaud, 1801) and *Perpolita* sp., as well as hydrophilic *Vertigo antivertigo* (Draparnand, 1801) and *Succinea putris* (Linnaeus, 1758). The considerable amount of shells belonging to *Vallonia pulchella* (Müller, 1774) and *Cochlicopa lubrica* (Müller, 1774), which inhabit unforested moderately humid biotopes of, and *Succinea putris* (Linnaeus, 1758), which dwells in highly humid temporary wetlands, indicates the increase in precipitation in the study area. It can be inferred that phytocenosis was close to a meadow type.

![Figure 6](image6.png)

**Figure 6.** Percentages of ecological groups in malacofaunal associations of the Tartat section deposits.

The freshwater species of ephemeral and permanent water objects, *Gyraulus rossmaessleri* (Auerswald, 1851) and *Gyraulus laevis* (Alder, 1838), appear at 0.1–0.05 m. The representatives of the Vertigo genus disappear from the thanatocenosis, while the amount of *Succinea putris* (Linnaeus, 1758) abruptly decreases. Beginning from 0.05 m depth and higher, singular shells are represented by those of land species *Cochlicopa lubrica* (Müller, 1774) and *Vallonia* sp. Contemporary mollusks have not been found in the study area.

**5. Discussion**

*5.1. Species of particular biogeographical interest*

The *Gastrocopta theeli* (Westerlund, 1877) species was found in this study. Shell morphology and dimensions are shown in figure 7 and presented in table 2.

![Figure 7](image7.png)

**Figure 7.** Morphology of *Gastrocopta theeli* shell.
Table 2. Dimensions of Gastrocopta theeli shell.

| Parameter       | Size (mm) |
|-----------------|-----------|
| Shell height    | 1.9       |
| Aperture height | 0.7       |
| Body whorl height | 1.1     |
| Shell cone height | 1.2     |
| Shell width     | 1         |
| Aperture width  | 0.6       |

In the southern Yenisei Siberia, the present-day geographic range of this species is limited by the town of Yeniseisk in the north [43]. In the Quaternary fauna of Eurasia, Gastrocopta theeli (Westerlund, 1877) is quite rare and is found, predominantly, in interglacial deposits. Shells of this species have been found in the Kazantsevian (Eemian) buried soil exposed on the shore of the Krasnoyarsk water reservoir in the Derba archeological district. It was also found in the Eemian deposits of Czechoslovakia, in the lower Pleistocene layers of the Kelniki section in Poland, and in the Likvinian (Strelitsa) alluvium of the Shekman’ section, upper Don River basin [21].

The first data on the distribution of Gastrocopta theeli (Westerlund, 1877) in the Holocene deposits of the Lake Baikal basin (predominantly southern part of the basin) has been provided in the publication by A. G. Fillipov et al. [44]. Later, shells of this species have also been found by A. F. San’ko and E. V. Akimova [20] when studying the Holocene deposits at the Listvenka Late Paleolithic multilayer site. The studies conducted by D. White et al. [14] have revealed the presence of this species in the Holocene deposits of the Lena River upper reaches. The finding of Gastrocopta theeli (Westerlund, 1877) shell in the Late Holocene deposits in the Bazaikha section is the first one in the area of Krasnoyarsk depression. The finding supports the relic, spotted character of its geographic range.

5.2. Palaeoenvironment reconstruction

Analysis of the successions of malacofaunal assemblages in the flood-plain deposits from river valleys of Yenisei River’s right tributaries and results of palynological studies of the Eleneva Cave reference section [24] have allowed us to perform the reconstruction.

The 2400 до 1650 cal yr BP deposits are characterized by the presence of shells belonging to 21 mollusk species: Pisidium casertanum (Poli, 1791), Lymnaea truncatula (Müller, 1774), Lymnaea peregra (Müller, 1774), Lymnaea sp., Gyraulus albus (Müller, 1774), Gyraulus laevis (Alder, 1838), Gyraulus rossovalessleri (Auerswald, 1851), Armiger crista (Linnaeus, 1758), Carychium minimum Müller, 1774, Succinea putris (Linnaeus, 1758), Succinella oblonga (Draparnaud, 1801), Oxyloma elegans (Risso, 1826), Succinea sp., Cochlicopa lubrica (Müller, 1774), Vallonia pulchella (Müller, 1774), Vallonia costata (Müller, 1774), Pupilla muscorum (Linnaeus, 1758), Gastrocopta theeli (Westerlund, 1877), Vertigo alpestris Alder, 1838, Punctum pygmaeum (Draparnaud, 1801), Perpolita hammonis (Strom, 1765), Fruticicola schreneckii (Middendorff, 1851), and Euconulus fulva (Müller, 1774). The composition of spore-pollen assemblage indicates that birch-pine forest-steppe was developed between 2400-1650 cal yr BP. Malacofauna dwell under a relatively cold and variably humid climate. Mean July temperature was +17.3 °C, while January temperatures ranged from −22.9 to −23.0 °C, duration of the frostless period ranged from 87 to 105 days. Annual precipitation was up to 450 mm, with total summer precipitation of no more than 280 mm.

The 1650-950 cal yr BP deposits are characterized by the relatively warm and moderately humid climate. The combination of heat and water availability caused the existence of predominantly land hydrophilic malacofauna: Vallonia pulchella (Müller, 1774), Vallonia costata (Müller, 1774), Vallonia sp., Succinea putris (Linnaeus, 1758), Cochlicopa lubrica (Müller, 1774), Vertigo antivertigo (Draparnaud, 1801), Vertigo sp., Euconulus fulva (Müller, 1774), as well as the presence of freshwater species of Lymnaea peregra (Müller, 1774) and Lymnaea truncatula (Müller, 1774). Based on the
palynological studies of the Eleneva Cave section, during the interval between 1650-950 cal yr BP the fraction of steppe assemblages increased in the vegetation on the southern slopes of the Krasnoyarsk depression. Mean July temperature was 18.0 °C, January temperatures varied from −19.0 to −19.3 °C, duration of the frostless period was 93–118 days. Annual precipitation ranged from 410 to 440 mm, with summer precipitation being up to 230 mm.

From 950 cal yr BP malacofauna is characterized by the lowest diversity and represented by two freshwater (Gyraulus rosmaessleri (Auerswald, 1851), Gyraulus laevis (Alder, 1838)) and five land (Succinea putris (Linnaeus, 1758), Cochlicopa lubrica (Müller, 1774), Vallonia pulchella (Müller, 1774), Punctum pygmaeum (Draparnaud, 1801), Perpolita sp.) mollusks. The composition of spore-pollen assemblage includes pine, birch, and forbs pollen, reflecting the landscapes of pine-birch forest-steppe. Climatic conditions corresponded to the present-day ones. Mean July temperature was +18.8 °C, January temperature was about −18.0 °C, the duration of the frostless period changed from 96 to 113 days. Annual precipitation was about 395 mm, with summer precipitation being up to 210 mm.

6. Conclusions

As a result of this study, it was established that the Late Holocene malacofauna of the Krasnoyarsk depression in the valleys of the Bazaikha and Tartat rivers was represented by 7 freshwater species: Pisidium casertanum (Poli, 1791), Lymnaea truncatula (Müller, 1774), Lymnaea peregra (Müller, 1774), Lymnaea sp., Gyraulus albus (Müller, 1774), Gyraulus laevis (Alder, 1838), Gyraulus rosmaessleri (Auerswald, 1851), Armiger crista (Linnaeus, 1758) and 15 terrestrial species: Carychium minimum Müller, 1774, Succinea putris (Linnaeus, 1758), Succinella oblonga (Draparnaud, 1801), Oxyloma elegans (Risso, 1826), Succinea sp., Cochlicopa lubrica (Müller, 1774), Vallonia pulchella (Müller, 1774), Vallonia costata (Müller, 1774), Vallonia sp. Pupilla muscorum (Linnaeus, 1758), Gastrocopta theeli (Westerlund, 1877), Vertigo alpestris Alder, 1838, Vertigo antivertigo (Draparnaud, 1801), Vertigo sp., Punctum pygmaeum (Draparnaud, 1801), Perpolita hammonis (Strom, 1765), Perpolita sp., Fruticicola schrenckii (Middendorff, 1851), Euconulus fulva (Müller, 1774). Fossil communities were dominated by species of the families Valloniidae Morse, 1864 and Lymnaeidae Rafinesque, 1815. Detection of the Gastrocopta theeli species shell in the late Holocene sediments of the Bazaikha section is the first such discovery in the Krasnoyarsk depression and confirms the relict, focal nature of the range of this species.

Paleoenvironmental reconstruction was enabled by using malacofauna as an environmental proxy, in addition to the results of a palynological study of the reference section “Eleneva Cave”. It was shown, that during the last 2500 years malacofauna in the valleys of Bazaikha and Tartat rivers developed in the background of gradual increase in heat availability and decreasing total annual and warm-period precipitation. The change in precipitation about 950 years ago caused the reduction of malacofauna diversity.

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