Structural features of the bark in young stems of *Betula ermanii* Cham. in the conditions of Yuzhno-Sakhalinsky mud volcano (Sakhalin Island)

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Abstract. In the present paper, the results of the study of the structural peculiarities of *Betula ermanii* growing in the setting of the Yuzhno-Sakhalinsky mud volcano are presented. A statistical analysis of the structural parameters of young stem bark has been conducted, which has made it possible to distinguish features dependent on extreme environmental conditions. Parameters of young stem bark have been elicited, which have higher than normal values: the thickness of periderm and phellem, the diameter and length of sieve tube elements, the specific number of crystals in bark parenchyma, the specific area of sclerenchyma in the bark. The structural response of the young stem bark of *Betula ermanii* is likely to have an adaptive nature.

1. Introduction
Like all other natural phenomena, mud volcanism phenomenon can affect the environment both positively and negatively. In particular, when underwater volcanoes erupt, the impact of mud volcanoes on the ecology of the Caspian Sea is very bad [1]. During the spring eruption occurs of 2001 in the Caspian Sea the death of a huge mass of anchovy and macro-eyed sprats, which live at a depth 50–100 m and more in an open deep part of the sea, was observed. Vegetation on the onshore mud volcanoes is scarce because the soil is very salty, an environmental condition in which few plants can survive. At the same time, such an environment may be good for some plant species.

Sakhalin is an island with unique ecosystems which have been formed under the influence of various extreme endogenous natural factors, one of which being mud volcanic activity. One of the largest and most active mud volcanoes of Sakhalin is the Yuzhno-Sakhalinsky mud volcano (YSMV). As a result of its activity, the mud volcano ejects onto the surface fluidified sedimentary rocks and forms a special landscape, altering the chemical composition of the substrata, as well as the composition of the ground air, due to the emission of gases from the eruptive centers and crevices [2]. The formation of vegetation in the vicinity of volcanic activity is closely associated with the living strategies of whole communities, as well as individual species. These strategies are aimed at raising the survival rate of plants under specific environmental conditions. Such species have developed various adaptive mechanisms, ensuring the adjustment of life processes to the stressful environmental conditions [3]. We believe that perennial plants – trees and shrubs growing on the volcanic deposits of the YSMV of different time periods – have also developed
certain adaptive mechanisms. The objective of the present study is to reveal adaptive structural peculiarities and divergences in the young stem bark tissue of *Betula ermanii* Cham. in the setting of the Yuzhno-Sakhalinsky mud volcano.

The stone birch (*Betula ermanii* Cham.) is one of the main forest-forming species in the Far East. This is a monoecious, deciduous, anemophilous large tree or shrub. The species has a wide ecological range, forms both single-species and mixed forests in the mountains and in the foothills, as well as busherwood – dwarf birch thicket – by the seashore and in the high mountain region. In mixed forests, one can mostly encounter it along with dark coniferous species (spruce, fir tree, and less frequently – with larch [4]. In the setting of a mud volcano, *Betula ermanii* grows on the border of the mud field in a birch-alder-willow tall-grass forest (figure 1). The diameter of tree trunks reaches 28–32 cm, the age of trees ranging from 180 to 205 years. The substrate on which the studied species grow is characterized by the following specific conditions: high alkalinity and sodium carbonate salinization [5], the presence of rare-earth and heavy metals.

![Figure 1](image_url)  
**Figure 1.** Birch-alder-willow tall-grass forest at the border of 2001 deposits of Yuzhno-Sakhalinsky mud volcano.

2. Materials and methods
The selection and fixation of stem samples from three species of *Betula ermanii* for anatomical analysis were performed on the YSMV and under the background conditions (typical of the species). Under the typical conditions, *Betula ermanii* shoots were sampled in the fir-stone birch herb-shrubby forest (the Susunayskiy Ridge, Sakhalin Island). The diameter of the sample tree stems was 17–18 cm, the age was 60–70 years.

The structural analysis of the microsections of young stems of *Betula ermanii* was performed by means of light microscopy, according to the standard methodological approach [6]. The
sample analysis was carried out using the equipment of the Laboratory of Plant Ecology and Geoecology of the Institute of Marine Geology and Geophysics, Far Eastern Branch of the Russian Academy of Sciences. The description of the bark tissues was made in accordance with [7]. In the course of the study, 27 quantitative parameters of Betula ermanii stem bark were analyzed for each habitat, their age being 1, 2, and 5 years. The sample volume for each parameter in each age group was no less than 32 measurements under the normal conditions and in the setting of a mud volcano. For each parameter, sample average value and its confidence interval were calculated (for confidential probability 95 %).

3. Results and discussion

The bark of a one-year-old stem of Betula ermanii at the end of the first growing season consists of: periderm, cortex, clusters of protophloem fibres and sclereids, primary and secondary phloem [8]. In young five-year-old stems, the histology and topography of the bark tissues do not change. By the age of five years, the thickness of the bark increases significantly due to the annual formation of new layers of phellem and secondary phellem and the sclerification of parenchyma.

The periderm is laid subepidermally, it includes multi-layer heterogeneous phellem, single-layer phellogen and one- or two-layer phelloderm (figure 2). In one-year-old stems, the periderm thickness in the YSMV setting, as compared to the norm, goes up by 18 % and reaches 115.51 ± 3.42 µm (the norm being 98.21 ± 2.02 µm). This increase occurs due to the fact that the phellogen forms more layers of phellem in the radial row. The same tendency can be observed in young stems, i.e. the periderm thickness in five-year-old stems increases by 55 % (82.29 ± 9.42 µm), as compared to the norm (53.27 ± 2.32 µm).

Figure 2. One-year-old stem structure of Betula ermanii. (A) Transverse section of the stem; (B) Transverse section of the bark. 1 – bark, 2 – xylem, 3 – pith, 4 – lenticel, 5 – epiderm, 6 – phellem, 7 – collenchymatous parenchyma, 8 – cortex ground tissue (parenchyma), 9 – sclereids, 10 – protophloem fibers, 11 – phloem.

The cortex consists of collenchymatous and ground parenchyma. The collenchymatous parenchyma has 2–3 layers, the cells have an oval shape. The ground parenchyma of the cortex is made up of isodiametric cells with large intercellular spaces. The ground parenchyma cells contain crystals of calcium oxalate. Such crystals can also be found in the radial and axial parenchyma of the phloem. In the setting of YSMV, the crystals in these tissues form large clusters. The specific number of crystals in one-year-old stems on the YSMV increases by 63 %
(120.94 ± 11.69 pcs/mm²), as compared to the norm (74.40 ± 2.68 pcs/mm²), and in young five-year-old stems the difference is 15 % (276.86 ± 16.93 pcs/mm² and 239.78 ± 11.07 pcs/mm² respectively).

The primary mechanical elements are represented by clusters of protophloem fibres and sclereids. The size and number of sclereids in parenchymal tissues increases with the age of the stem. The specific area of sclerenchyma (particularly, sclereids) is also greater in the setting of the YSMV in the bark of young stems. At the age of five years, on the YSMV, the specific area of sclerenchyma is 42.38 %, whereas under the background conditions it is 39.61 %.

The secondary phloem in a one-year-old stem consists of sieve tubes and companion cells, axial and radial parenchyma. The sieve tubes on the cross-section cut are elongated in the tangential direction. The sieve tubes and axial parenchyma are located diffusely. The axial and radial parenchyma contains crystals of calcium oxalate. The phloem rays are homo- and heterocellular, with 1, 2, and 3 rows. The thickness of the conducting phloem in 1- and 2-year-old stems on the YSMV and under the background conditions does not differ. In the setting of the YSMV, in a five-year-old stem this parameter increases by 38 %, as compared to the norm, and totals to 59.65 ± 2.27 µm and 43.38 ± 2.58 µm respectively. In the stems of all ages on the YSMV, the radial and tangential diameters of the sieve tubes are higher than normal – by 19–38 %. Moreover, in the setting of the YSMV, in young stems the length of sieve tube segments increases by 11–17 %. The quantitative parameters of phloem parenchyma in young stems have close values under the normal conditions and on the YSMV.

Thus, in the setting of the YSMV, in the bark of young stems of Betula ermanii, individual structural elements have quantitative differences. Most structural divergences from the parameters characteristic of the background conditions are associated with their increase. Due to the increased number of phellem layers in young stems of Betula ermanii on the YSMV, the periderm becomes thicker. The depositing of metabolic products is intensified – they are stored in the form of calcium oxalate crystals. Sieve tube segments transporting aqueous solutions of synthetats, in the setting if the YSMV, have larger spaces and greater length. It is possible to assume, that in the stems of Betula ermanii in the setting of a mud volcano the photosynthetic rate increases, which results in a subsequent increase of the amount of organic matter (more than under normal conditions), intensification of its transport, and consequently there arises a need for an additional disposal of excess plastic material. Perhaps, the combination and joint effect of otherwise disassociated factors on the YSMV determines the adaptive structural transformation of specific bark tissues of Betula ermanii.

4. Conclusion
Summarizing what has been said, the inner structure of young stems of Betula ermanii in the setting of the Yuzhno-Sakhalinsky mud volcano (it terms of their histology) does not differ from that under the background conditions. No abnormal structures have been revealed in the bark of young stems in the setting of the YSMV. The statistical analysis of the structural parameters of the bark in young stems of Betula ermanii in the setting of the YSMV and under the background conditions shows a distinct response of the inner structure, which has an adaptive nature. The structural divergences manifest themselves in the enhanced thickness of the periderm due to the increased number of phellem layers; in the increased rate of the depositing of metabolic products in the form of calcium oxalate crystals; in the greater diameter and length of the sieve tube segments.

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