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Geographical Variants of the Siberian Alpine Vegetation for the "Circum-Boreal Vegetation Map"

Galina N. Ogureeva
Faculty of Geography, Lomonosov Moscow State University, Moscow 119991, Russia

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Abstract: The vegetation cover in highlands is rather peculiar and complicated in its structure. The experience gained in mapping of alpine vegetation shows that the schematic small-scale maps reflect only the very common features. In boreal forest mountains of Siberia there are four systems of alpine vegetation including alpine-meadow, goltsy-tundra, island near the Pacific Ocean and tundra-steppe ones. Every system is represented by several geographical variants, characterized by regional phytogeographical peculiar features of this vegetation. The geographical variant includes a number of altitudinal belts (zones), each of them has its floristic peculiarities and complexes of plant formations (for instance, Altai-Sayan variant composes of subalpine-alpine-subnival-nival belts). Such geographical variants of alpine vegetation may be indicated as chorological units on a new Circum-Boreal Vegetation Map. Under discussion is the possible use of ecological-geographical approach to reflect the alpine vegetation as chorological (structural) units of the vegetation cover being exemplified by high mountains of the Siberia. This map may be more informative in terms of regional peculiarities in alpine vegetation within the boreal biome.

Key words: Biodiversity, mapping, high mountain (alpine) vegetation, altitudinal zonality type.

1. Introduction

The vegetation at mountainous territories of Russia has been so far studied irregular especially in its interpretation on available biogeographical maps. Zonal regularities in vegetation distribution are schematically shown on maps; the vegetation cover and regional specific character of altitudinal subzones are not differentiated. For instance, the diversity of alpine vegetation is presented by 8 units as combined with the zonal tundras on the small-scale vegetation map for higher schools (map scale 1:4,000,000) [1]. Only pine elfin woodlands (stlanik) are distinguished as an independent belt. Due to a persisting lack of exact information on classification of altitudinal structures of mountain vegetation and regularities in its reflection on small-scale vegetation maps, there still remain uncertainties about the diversity of vegetation and its geographical distribution. However, the geography of the high-mountain vegetation is discussed in phytogeography repeatedly [2-4].

There are several systems of high-mountain vegetation in the Russia. The differences between systems of alpine vegetation in highlands of the Siberia are determined, on the one hand, by bioclimatic conditions suitable for high mountain formations, and, on the other hand, by the floristic composition of plant communities, which have being appeared in the process of historical development of mountain territories [5, 6]. The highlands are chiefly affected by the atmosphere, circulation and the air mass transfer. The vegetation cover of high mountain belts reveals differences to a lesser extent as compared to that in the middle part of altitudinal zonality in dependence on local natural conditions, what serves as evidence of regional differences and specific character of definite altitudinal zonality types.

The Pacific variant of goltsy-tundra system is typical for high mountain areas of the Beringian sector

Corresponding author: Galina N. Ogureeva, professor, research fields: phytogeography and biodiversity, mapping vegetation. E-mail: ogur02@yandex.ru.

the North-eastern Asia. The specifics of this high mountain vegetation determined by the regime of temperature and precipitation, snow cover, activity of volcanoes and other factors [6, 7]. The tundra-steppe system of high-mountain vegetation of the cryoxerophytic type is considered separately for the south-eastern Altai [8, 9]. It is connected with the history of the development of mountain territories, repeatedly exposed to Quaternary glaciations. The high elevation of the territory and the modern regimes of natural conditions, influenced by vast arid areas of Mongolian desert, determine the xerophytic vegetation appearance of all high-altitude belts, including tundra-goltsy communities.

High mountain vegetation of the Siberian Mountains is distinguished both by the uniqueness and the high level of its biodiversity. Having prepared the legend of a new schematic small-scale map of Circum-Boreal Vegetation [10], approaches were urgently required to generalize the available data about the vegetation structure in high mountains in view of elaborating the classification of altitudinal structures of alpine vegetation and determining their botanical content and ecological-geographical relationships. The present paper is aimed at showing the possibilities of an ecological-geographical approach to reflect the alpine vegetation structure on a small-scale map as based upon chorological mapping units.

2. Materials and Methods

The mountains occupy more than 45% of the total territory in Siberia. The altitudinal zonality is determined through integral manifestation of latitudinal and altitudinal regularities in the vegetation distribution. When mapping this vegetation cover, it is necessary to bear in mind its complicated pattern and distinguish chorological subzones. The system of spatial or territorial structure of the vegetation cover suitable for mapping of alpine vegetation at small scale proves to be conducive to the vegetation cover geography.

The central place in the structure of mountain vegetation in the Siberian Mountains occupies regional altitudinal zonality spectra or types, including the successive ranks of the high altitude vegetation belts. An altitudinal zonality type is considered as a basic chorological unit of the vegetation structure in high mountains [11]. The geographic-typological principle serves as a basis for classification of altitudinal zonality types, the latter being combined into large hierarchical categories of altitudinal zonality systems are divided into groups and classes. Regional groups of altitudinal zonality types compose of altitudinal systems of formations, which are identical in prevalent classes. In every group the types are distinguished according to the phytocoenotic composition of formations being combined in terms of genetic biocoenoses and structural morphology, thus reflecting regional features of altitudinal zonality spectra under definite hydrothermic conditions. The groups come in classes and subclasses of altitudinal zonality types to indicate structural-genetic peculiarities of predominant vegetation types as complexes of formations, which are genetically connected with each other.

The map "Zones and Altitudinal zonality types of Vegetation in Russia" depicts the basic ecosystem diversity of the Siberian Mountains [11]. The legend of this map contains 72 altitudinal zonality types as classified into 18 groups, 9 subclasses and 5 classes, represented by cartographic model of diversity altitudinal zonality spectra of the mountain vegetation of the country. The Siberian portion of this map includes 29 mapping units (altitudinal zonality types), united in 5 groups and 2 classes of types (Table 1).

The map reflects regularities in altitudinal zonality of mountain vegetation and its regional features. Special attention is paid to different types of vegetation structures, the floristic and phytocoenotic diversity of altitudinal belts and the altitudinal zonality spectra on the whole. Each group of

Table 1 Classification of altitudinal zonality types of the Siberian mountain boreal vegetation.

Classes of types	Subclasses of types	Groups of types (types)
Hypoarctic types	Hypoarctic (taiga)	Central Siberian (1) Verkhoyansky Range-Kolyma (6) Northern Okhotian (3)
Boreal (taiga) (coniferous forest types)	Ural-Southern Siberian	Altai-Saiany (4) Tuva-Southern Transbaikal (3) Baikal region (3)
	Eastern Siberian (Angaridian)	Transbaikal (5) Aldan (4)
	Okchotian	South Okhotian (5)
	Beringian	Islands of Northern part of the Pacific ocean (2)

altitudinal zonality types is characterized by its structure, floristic and phytocoenotic diversity including the specific character of high mountain plant communities.

Geographical variants of alpine vegetation are a reflection of regional systems of altitudinal zonality types in the Siberian Mountains.

3. Results and Discussion

3.1 The Upper Forest (Tree) Line

The high mountain belts are spatially and functionally connected with those situated lower their boundary, what was repeatedly marked in Refs. [2, 3, 5, 6, 12] etc.. Their specific character is dependent on floristic differences in alpine plant communities appeared in the process of mountain building to a greater extent as compared to their coenotic structure.

The upper forest (tree) line is an important integral indicator of climatic conditions, limiting a distribution of tree species and the development of high-mountain vegetation. The lower line of high mountain vegetation coincides with the upper boundary of the mountain-taiga belt. The upper tree line in different regions of Siberia is determined by thermal conditions, it is dependent on moistening degree and regime of precipitations, the absolute height being corrected by the thickness of the snow cover. It is an important integral index of the altitudinal zonality type in phytogeographical space of the mountain territory. In Siberian highlands its position varies in a wide range. It is rather low being connected with hypoarctic types and that of island belt near the Pacific Ocean (about 800 m), the most upper position of the tree line is observed in mountains under conditions of dry continental climate in the southern portion of Siberian mountains (at a height of 2000-2400 m). This line can change within every group of altitudinal zonality types. Graphic models help to make its comparative analysis and define such changes in groups of types (Fig. 1).

3.2 Structure and Geographical Variants of the High Mountain Vegetation

There exist five high mountain vegetation systems in highlands of Siberia. They represent different types of ecosystems, and their provincial features are explained by geographical peculiarities of the mountain territories [5, 6]. Differences between such systems are determined by bioclimatic conditions as well as by a coenoses set and floristic composition of the main plant communities (Table 2). Within the zone of boreal forests four systems of alpine vegetation are distinguished (I-IV); the arctic system is characteristic of tundra zone.

3.3 Characteristic of the Systems and Geographical Variants of High Mountain Vegetation of the Siberia

The alpine-meadow vegetation system is observed under conditions of sufficient moistening, where the snow cover is rather thick, well drainage of soils, the permafrost is absent and the relief of alpine type. Within the subalpine belt, forb meadows are dominant in combination with open woodlands, parks and

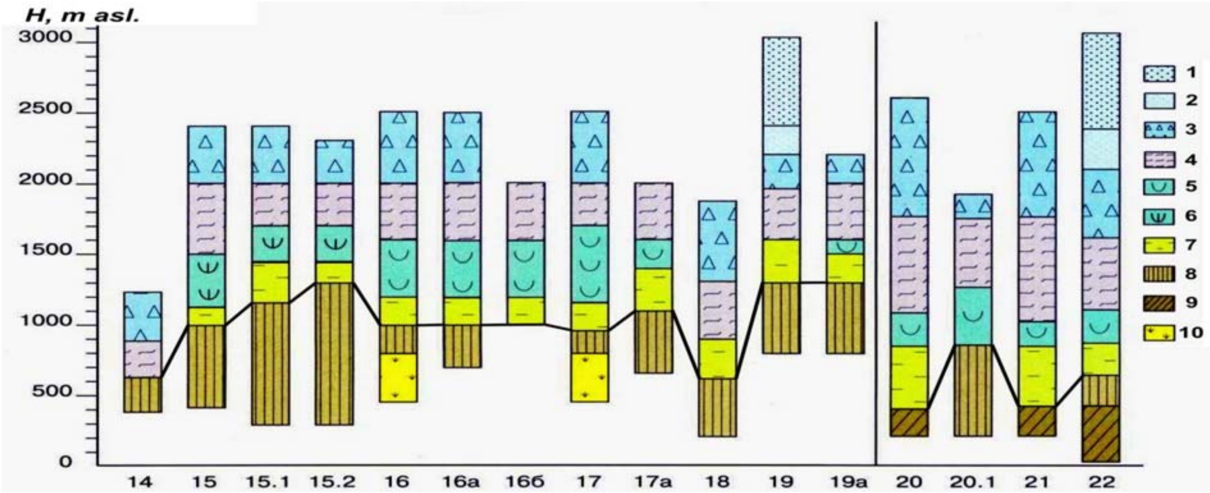


Fig. 1 The altitudinal zonality types (14-22—number of type) on the map "Zones and Altitudinal Zonality Types of Vegetation in Russia" [11].

Verkhoyansky Range-Kolyma (North Angarida) group of types, types—14: Polousnyi Range; 15: Verkhoyansky Range; 15.1: West Verkhoyansky variant; 15.2: South Verkhoyansky variant; 16: Yana Range; 16a: Chersky Range; 16b: Elginskoye plateau; 17: Indigirka Range; 17a: Nerskoye plateau; 18: Omolon Range; 19: Oimyakon; 19a: Oimyakon plateau; 20: Kolyma Range; 20.1: Olsky basalt plateau; 21: Judoma Range; 22: North Okhotian. The altitudinal belts—1: nival; 2: subnival; 3: goltsy; 4: mountain tundras; 5: subgoltsy strips; 6: Pine stlanik; 7: stlanik with *Alnus fruticosa*; 8: stlanik and dwarf larch forests; 9: open larch woodlands; 10: forest-steppes. Line—the position of the upper forest (tree) line.

Table 2 The geographical variants of the high mountain vegetation of the Siberia and their bioclimatic characteristics.

The systems and geographical variants (v.) of the high mountain vegetation	Climatic parameters			The tree-line, (m, a.s.l.)
	Mean annual temperature, °C	The sum of air active tempera-tures ($\sum t > 10$ ºC)	Mean annual precipitation (mm)	
The goltsy-tundra vegetation system				
The Central Siberian v. (the Putorana Mts.).	–9.3º-10.2º	400º-1,000º 550º-690º	350-550	500-600
The Northern Angaridian (Verkhoyansk-Kolyma) v.	–13.8º-15.7º –16.4º-16.6º–(Oyamaykon)	200-680º 800-1,200º (in the low belts)	720-800 (in the goltsy-tundra belt), 150-600 (on the slopes), 150-200 (in a river valleys and basins)	400-800, 1,100-1,450, to 1,600
The Transbaicalian v. (South Angarida)	–1.6º-3.8º –0.5º-1.5º –6.0º-8.7º –11 ºC (in the basins)	1,600º-1,800º	250-350 (in the steppe belt, in the basins), 700-800 (on the slopes), 800-1,000 (in the Highlands)	1,100-1,400
The South Okhotian v.	–2.3°-6.8°	1,200-1,500°	500-700 (near the sea), 350-450 average	1,100-1,300
The alpine-meadow vegetation system				
The Southern Siberian (Altai-Sayan Mts.) v.	–0.2º-1.5º –4.5º-6.3º	1,850-2,200º 500-1,300º (in a valley of the river Katun)	250-500 (in the basins), 1,000-1,500 (on the slopes), 1,500-2,000 (in the Highlands)	2,000-2,100 (on the northern ridges), 2,100-2,300 (on the southern ridges)
The North Pacific or Beringian vegetation system				
The Northern Okhotian v.	–7º-9º	700-800º	average 300-500, 800 (in the Highlands)	350-400 900-1,100
The Kamchatka v.	–0.2º-1.3º –2.4º-5º	1,200-1,600º 700-900º	950-1,250	700-850, 1,100-1,300
The tundra-steppe vegetation system				
The Mongolian-Altai v.	–3º-9º	1,100-1,200º, 825º (at 2,000 m)	200-500 (in the Highlands)	2,000-2,200

shrub-yernik communities. In the alpine belt apart from meadows are widespread different types of tundra plant communities including meadow grass, sedge-grass and shrubby-lichen. Subnival and nival belts are also distinguished. This system has the following geographical variant.

3.3.1 The Southern Siberian (Altai-Sayan Mts.) Variant (I)

The mountains in southern Siberia (Altai, the western portion of Sayan mountains) characterized by warm and wet climatic conditions exhibit the most complete spectrum of altitudinal vegetation subzones stretching from steppe, expositional forest-steppe, mountain taiga to alpine and the belt of glaciers. The subalpine belt is situated at a height of 1,800-2,200 m in northern and central regions being higher than 2,400 m in southern mountain ridges. The forb meadows (*Trollius altaicus*, *T. asiaticus*, *Anemone crinita*, *Aquilegia glandulosa*, *Sanguisorba alpine*, *Trisetum altaicum*) in combination with tall-herb meadows (*Rhaponticum carthamoides*, *Alfredia cernua*, *Saussurea latifolia*), larch open woodland (*Larix sibirica*) and shrub communities predominate in the vegetation cover. The shrub communities—yerniks (*Betula rotundifolia*, *Salix glauca*, *S. krylovii*) are included into an independent subzone at a height of 2,100-2,400 m. The alpine belt (2,200-2,600 m) is represented by alpine meadows (*Ranunculus altaicus*, *Viola altaica*, *Gentiana uniflora*, *G. grandiflora*, *Primula nivalis*) and a great variety of plant communities of mountain tundra (shortgrass meadow, sedge-grass, shrubby-lichen with *Dryas oxyodonta*). The subnival belt (2,600-3,000 m) is situated in the area with the thick snow cover and distribution of separate groups of orophytes (*Saxifraga oppositifolia*, *Waldcheimia tridactylites*, *Claytonia joanneana*) and mat (*Sibbaldia procumbens*) with fragments of mountain tundra. The subnival-nival belts are situated at a height of 3,000-4,500 m.

The goltsy-tundra vegetation system is widely distributed in mountains of Siberia. In the northern part of boreal zone the vegetation cover is enriched with hypoarctic phytocoenotic complexes that have being developed since the time of natural landscape formation in early Pleistocene [13]. Widespread are larch open woodlands with some closed forest communities; the landscape is represented by hypoarctic oligotrophic shrubby, shrub-yernik communities and willow tundras. The high mountain area of the Suntar-Chayata Ridge represents a phytogeographical boundary between the mountain tundra vegetation of continental and coastal types inside hypoarctic zone of Siberia [14].

The high mountain vegetation in the northeastern hypoarctic part of Siberia is developed under conditions of ultracontinental climate (Table 2). This territory is considered as a pole of cold in the northern hemisphere and due to winter anticyclone the permafrost remains for a long time. Larch open woodlands with *Larix cajanderii* are widely spread as represented by cryogenic variant of larch taiga. Alpine vegetation occupies vast areas on peaks and slopes of mountain ridges.

3.3.2 The Central Siberian Variant (the Putorana Mts.) (II)

The trapps plateau Putorana (1,700 m) is situated within the hypoarctic belt of middle Siberia. Lichen larch forests (*Larix gmelinii*, *L. sibirica*) are predominant in the mountain-taiga belt. The upper tree line is at a height of 500-600 m in the north and 580-700 m in the south of this plateau. The subgoltsy belt (450-800 m) consists of larch open woodlands (*L. gmelinii*), lichen, grass, shrub (*Alnus fruticosa*), shrub-yernik (*Betula nana*, *B. exilis*, *Salix philicifolia*, *S. hastate*, *S. lanata*, *S. lapponum*) and sometimes moss undergrowth are also met. The mountain tundras (800-1,350 m) is distinguished as spotty (*Dryas octopetala*, *Cassiope tetragona*, *Carex bigelowii*, *C. saxatilis*, *Salix polaris*), shrubby (*Vaccinium uliginosum*), shrubby-lichen (*Dryas octopetala*, *Novosiversia glacialis*, *Deschampsia caespitosa*, *Luzula confuse*, *Saxifraga* *bronchialis*) and moss one. In the area higher than 1,350 m there exist goltsy, large stony placer deposits covered by crustaceous lichens.

3.3.3 The Northern Angaridian (or Verkhoyansky-Kolyma) Variant (III)

The system of altitudinal belts includes mountain forest-steppe, hypoarctic taiga, subgoltsy open woodlands, mountain tundra, goltsy-tundra, subnival and nival ones (Fig. 1). The upper tree line is at a height of 900-1,500 m, being higher than 1,300-1,500 m in Oimyakon tableland. Within the subgoltsy belt (1,400-1,600 m) larch open woodlands, shrubs (*Pinus pumila*, *Alnus fruticosa*, *Betula divaricata*, *Rhododendron aureum*, *R. redowskiana*) are met together with the areas covered by cryophytic steppes (*Potentilla multifida*, *Poa stepposa*, *Festuca auriculata*, *Artemisia lagopus*). In the upper part of this belt are dominant stlanik and alder elfin woods with shrubs (*Rhododendron aureum*, *R. parvifopium*) and lichen combined with yernik-willow undergrowth (*Salix krylovii*), bogs and stony placer deposits. In mountain tundra belt (1,100-2,000 m) the landscape surface is represented by lichen (*Cetraria nivalis*, *Alectoria ochroleauca*) and shrubby (*Dryas punctata*, *Salix cuneata*, *Cassiope ericoides*, *C. tetragona*) tundras in combination with *Betula divaricata*.

In grassy tundras, there are sedge (*Carex stans*), cotton-grass, *Cobresia bellardi*-*Carex rupestris* communities and fragments of cryophytic steppes. The goltsy belt (higher than 2,000 m) is stretching in peaks of mountain ridges covered by lichens with some fragments of mountain tundras and stony placer deposits, which are also covered by crustaceous lichens (*Rhizocarpon geographicum*, *Haematomma ventosum*, *Umbellicaria*). The subnival belt occupies mountain slopes of Suantar-Khayat Range at a height of more than 2,200 m. Lichens and some groups of arctic and arcto-alpine plant species (*Minuartia*, *Arenaria*, *Androsace*) are distributed among stony and moraine areas. The nival belt is situated at a height of more than 2,500 m [14].

The three-dimensional altitudinal zonality type is typical for continental mountains of the sothern part of the Siberian boreal zone, submitted by larch taiga belt, above the stlanik subbelt, mountain tundra belt and goltsy. Two variants of alpine vegetation are in this mountain territory.

3.3.4 The Transbaikalian (South Angarida) Variant (IV)

The goltsy-tundra system includes the subgoltsy belt of larch light forests and stlanik (pine elfin wood). Such plant species as heather (*Loiseleuria procumbens*, *Cassiope tetragona*, *Diapensia abovata*, *Phyllodoce caerulea*, *Rhododendron redowskianum*) and continental arctic species (*Dryas punctuta*, *Salix cuneata*, *Pedicularis adamsii*, *Oxytropis nigrescens*) are typical for the east-siberian mountain tundras. In wet areas the sedge-moss (*Carex sochaveana*), sedge-cotton grass mountain tundras are developed. In high altitude surface predominate crustaceouse lichens, in the downsituated surface are prevailing the fruticose lichen tundras (*Cladonia alpestris*, *Alectoria ochroleuca*, *Cetraria nivalis*). In the goltsy belt the vast areas of stony deposits are covered by crustaceous lichens and groups of psychrophytes, which are floristically linked with Okhotian region [15]. The small meadows of alpine type with the cryophytic psychrotrophytes (*Rheum compactum*, *Angelica saxatilis*) are developed near the snow line.

3.3.5 The South Okhotian Variant (V)

In the southern part of Okhotian sector within the mountain taiga are predominant dark coniferous forests of okhotian formations (*Abies nephrolepis, Picea ajanensis*). The high mountain vegetation occupies small areas. In the subgoltsy belt there is a strip of spruce, larch-spruce, birch (*Betula lanata*) thin forests, which are replaced by pine stripe (stlanik—*Pinus pumila*) and elfin-wood (*Alnus fruticosa*). The low bush tundras (*Cassiope ericoides*, *Rhododendron redowskianum*, *Ledum macrophyllum*, *Vaccinium uliginosum*, *V. vitis-ideae*, *Hierochloa alpine*) are widespread, as well as moss and lichen tundras with such species as *Selaginella* spp., *Claytonia acutifolia*, *Artemisia lagocephata*, *Dicentra peregrinum*. Thus, the flora of high mountains communities is characterized by combinations of oceanic (*Mertensia rivularis*, *Claytonia eschoscholtzii*) and continental elements (*Dryas ajanensis*, *Silene stenophylla*), the latter being prevailed in open goltsy, but later spread—within the subgoltsy belt in the oceanic areas [16].

3.3.6 The North Pacific or Beringian Vegetation System

This system is under the influence of the Pacific Ocean climate regimes, including monsoons. It is characterized by: low forest boundary, a wide belt of stlanik and open crook-stem birch forests and the mountain heaths tundras. This system is presented in the altitudinal zonality types of the northern part of Asian continent: the Koryakiy Highlands, the Northern Kurile Islands and the Kamchatka.

3.3.7 The Northern Okhotian Variant (VI)

The north-Okhotian group of altitudinal zonality types is related to Subpacific region [6]. The climate is affected by the Arctic moist air mass from the Pacific Ocean and cold air mass in the winter, being highly changed in a distance from the ocean. In the vegetation cover of all the belts the continental and oceanic flora elements are interacted in the composition of plant communities. The upper tree line is at a height of 350-400 m in mountain ridges near the coast being higher than 900-1,100 m with the distance from the ocean coast. In the subgoltsy belt (600-800 m) larch open woodlands with *Larix cajanderii* and *Pinus pumila* are distributed. A strip of stlanik and alder occupies more than 50% of this belt. Widespread are also birch communities (*Betula lanata*) with alder, mountain ash and *Betula exilis*, *B. divaricata*. In the mountain tundra belt, situated at a height of more than 800 m near the oceanic coast and 1,100 m far from it, lichens (*Cladonia alpestris*, *C. amaurocraca*, *C. sylvatica*, *Cetraria nivalis*), shrubby-lichen (*Empetrum nigrum*, *Rhododendron aureum*), grass-lichen and moss (*Aulacomnium turgidum*, *Rhytidium rugosum*) tundras are prevalent. The shrub tundras are widespread in this belt. They are characterized by the participation of the Okhotsk-Kamchatka plant species (*Cassiope ericoides*, *Rhododendron redowskianum*, *Saxifraga redowskiana*, *Pedicularis oederi*). The wet, grass-moss, spotty, sedge-moss tundras are widely spread as well. Higher than 1,400-1,500 m, there are goltsy, stony tundra with crustaceous lichens (*Rhizocarpon geographicum*, *Haematomma ventosum*, *Umbellicaria*), stony and talus deposits. Tundra nival meadow areas are located near the snow line.

3.3.8 The Kamchatsky Variant (VII)

The altitudinal zonality in mountain systems of Kamchatka, northern Kuril Islands and Koryak Upland is affected by the regime of tectonic structure and the atmosphere over the Pacific Ocean. Just this fact determines the specific character of altitudinal zonality of the above mountains: a low position of the upper tree line, predominance of birch forests (*Betula ermanii*) and meadows, huge areas of mountain tundra. The upper tree line in the coastal area is at a height of 250-300 m (Kuril Islands) being elevated to 700-900 m in a distance from it and 1,100-1,300 m in some volcano. A strip of birch and light forests is situated higher than 800-900 m. They are the oldest forests in Kamchatka and diverse in their composition being represented by bamboo, shrubs, grass and pine elfin wood. The birch forests include a number of such species as *Cypripedium yatabeanum*, *Cimicifuga simplex*, *Majanthemum kamtschaticum*, *Daphne kamtschatica*, etc. to be practically absent out of this belt. There are also meadow lands covered by tall-herb plants (*Filipendula kamtchatica*, *Senecio palmatum*, *Angelica ursina*, *Heracleum lanata*). The subbelt of pine elfin wood (Pinus pumila) is at a height of 750 m, but in central regions it starts at 1,100-1,400 m. The plant communities include *Rhododendron kamtchaticum*, *R. aureum*, *Betula divaricata*, *B. exilis* as well as *Alnus kamtschatica* and

Sorbus sambucifolia. The belt of mountain tundra embraces the area at a height of 1,400-3,000 m, being represented by *Diapensia*, *Louseuleuria*, *Empetrum nigrum*, *Arctous alpine*, *Phyllodoce aleutica*, *Cassiope lycopodioides*, *Dryas kamtchatica*, *Salix arctica*, *Rhododendron kamtchaticum*, *R. redowskianum*. Fragments of alpine meadows are met everywhere (*Anemone sibirica*, *Ranunculus altaica*, *Pedicularis capitata*, *P. Oederi*), the amount of which becomes greater at a height of 2,500-2,800 m, where they are developed in combination with mountain lichen and herb-shrubby tundras. The subnival belt with stony deposits is at a height of 2,800-3,000 m and changes by the belt of gletchers.

The tundra-steppe vegetation system in Russia occupies a small part of the mountains of the Southern Siberia (south-eastern Altai and Tuva) and a considerable area in the Mongolian Altai Mountains. This system is developed under conditions of strong continental climate, low air temperatures, the extreme dryness in all altitudinal belts and the general high lands. The sum of average annual precipitation is lower than the amount of a potential evaporation. The strong reduction or absence of the boreal forest belt (taiga belt) as well as the common xerophytisation of all belts vegetation are characteristic for the altitudinal zonal types. The next belts are characterized for the Highlands: cryophyte steppes and mountain tundra-steppes (tundra-heath, Cobresia communities, sedge hillocks combined with mountain tundras or formed phytocoenotic "tundra-steppe" complexes), mountain tundras, subnival and nival.

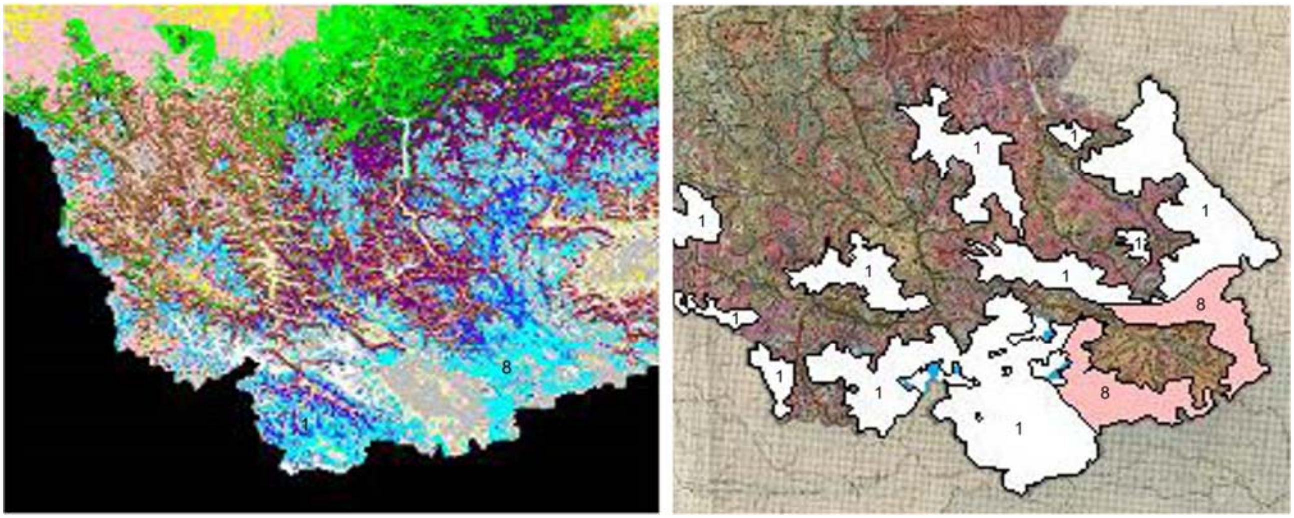
3.3.9 The Mongolian-Altai Variant (VIII)

Within the alpine-tundra zone, it is noted a large variety of moss-lichen tundras with fragments of alpine meadows, which are widely spread (2,500-3,200 m). Plant communities with *Betula rotundifolia,* meadows consisting of *Geranium albiflorum*, *G. pseudosibiricum* are prevailed in the subalpine belt. Among mountain tundras the low bush tundra (*Dryas oxyodonta*), tundra-steppe (*Festuca kryloviana*, *Ptilagrostis mongolica*, *Carex stenocarpa*), Cobresia meadows (*Cobresia myosuroides*, *C. humilis*), herb-sedge-willow (*Carex melanantha*, *C. stenocarpa*, *Carex rupestris*) are predominant. The nival belt embraces the area located from 2,800 to 3,970 m and consists of alpine meadows and cryophytic cushion plant formations (*Sibbaldia tetrandra*, *Saxifraga oppositifolia*, *S. cernua*, *Draba alpine*, *Dracocepalum imberbe*, *Sagina saginoides*).

Like that, eight geographical variants represent the high mountain vegetation in the Siberia, each of which is associated with the formation and development of the mountain territories in specific bioclimatic conditions and has its own combination of plant communities, peculiarities of their diversity and floristic compositions.

The experience to show macrostructures (macro-combinations) of mountain vegetation on schematic small-scale maps has been so far examined insufficiently [1, 3, 9, 11]. Only the alpine and subalpine vegetation was reflected in detail on the vegetation map of Europe at a scale of 1:2,500,000 produced in 2000 [17]. The legend of this map contains three zones represented by high mountain vegetation and tundras. The zone of "Arctic deserts and subnival-nival vegetation" (A) includes three mapping units of subnival vegetation; in the zone of "Arctic tundra and alpine vegetation" (B), there are 26 geographical variants of alpine vegetation and in the zone of "Subarctic and subalpine vegetation" (C), 41 variants of subalpine open woodlands. Thus, 70 typological subzones of vegetation found their reflection on the map within three altitudinal zones including nival, alpine and subalpine ones.

However, in the given paper under discussion is a small-scale map of Circum-Boreal Vegetation, (map scale 1:7,500,000), that has no possibility to present a wider appreciation of regional peculiarities in high mountains. The vegetation of each belt can not be shown on a map as independent units. The geographical variants represent a specific vegetation



(a) (b)

Fig. 2 An example of displaying the alpine vegetation in the Altai Mountains; (a) a fragment of the vegetation map according to information from space image [18]; (b) a fragment of the vegetation map showing geographical variants of vegetation in the Altai Highlands [9]: I—the Southern Siberian (Altai-Sayan Mts.) variant and VIII—the Mongolian-Altai variant.

structure, which may be shown on the map as chorology units. As an example, a feature of the south-Siberian variant of alpine vegetation is discussed to show possibilities of its reflection on a small-scale schematic map of the Circum-Boreal Vegetation (Fig. 2).

4. Conclusions

The structural geobotany as one of the trends in phytocoenology was more profound investigated thanks to mapping of the vegetation cover with the aim to identify its territorial distribution. Macrostructures of the vegetation cover in mountains are successfully specified as based upon the cartographic approach. Geographical types of vegetation serve as evidence of identifying the regional systems of altitudinal zonality in mountains of Siberia. Just these types are used to reflect the circum-boreal vegetation on a small-scale schematic map. As an example, the characteristics of south-Siberian variant of alpine vegetation is discussed to show possibilities of its reflection on a small-scale schematic map of the circumboreal vegetation.

It is suggested to show geographical variants of high mountain vegetation as structural units based on a geographical principle. It may be as a system of high-mountain vegetation for large regions. Each variant has its own provincial features associated with landscape structure of a territories and history of its development. For all proposed geographical variants detail, characteristics of high mountain belts and typical plant species are developed.

It may be eight such variants for the Siberia:

(1) The alpine-meadow vegetation system. Variant:

I. The southern Siberian (Altai-Sayan Mts.) v. (Characteristics of high-mountain vegetation of the Altai as an example of mapping unit for the Circumboreal vegetation map).

Nival (*Waldheimia tridactylites*, *Lupinaster eximium*, *Saussurea glacialis*)-alpine (alpine tundra, meadows—*Ranunculus altaicus*, *Seseli monstrosa*, *Schulzia crinita*. *Doronicum altaicum*, *Sibbaldia procumbens*)-subalpine (meadows—*Rhaponticum carthamoides*, *Aquilegia glandulosa*, *A. sibirica*, *Trollius altaicus*, *Geranium albiflorum*; Siberian pine, Siberian larch open woodlands; dwarf birch thickets–*Betula rotundifolia with Salix glauca, S. vestita*).

(2) The goltsy-tundra vegetation system. Variants:

II. The Central Siberian v. (the Putorana Mts.).

III. The Northern Angaridian (or Verkhoyansky-Kolyma) v.

IV. The Transbaikalian (South Angarida) v.

V. The South Okhotian v.

(3) The North Pacific or Beringian vegetation system. Variants:

VI. The Northern Okhotian v.

VII. The Kamchatsky v.

(4) The tundrã-steppe vegetation system. Variant:

VIII. The Mongolian-Altai v.

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