The Far North: Plant Biodiversity and Ecology of Yakutia

PLANT AND VEGETATION

Volume 3

Series Editor: M.J.A. Werger

For other titles published in this series, go to www.springer.com/series/7549

The Far North: Plant Biodiversity and Ecology of Yakutia

E.I. Troeva, A.P. Isaev, M.M. Cherosov, and N.S. Karpov

Russian Academy of Sciences
Siberian Branch
Institute for Biological
Problems of the Cryolithozone

Springer

Editors
E.I. Troeva
Russian Academy of Sciences
Siberian Branch
Institute for Biological
Problems of the Cryolithozone
41 Lenin Ave.
Yakutsk
Russia 677980
etroeva@mail.ru

A.P. Isaev
Russian Academy of Sciences
Siberian Branch
Institute for Biological
Problems of the Cryolithozone
41 Lenin Ave.
Yakutsk
Russia 677980
forest_forest@ibpc.ysn.ru

M.M. Cherosov
Russian Academy of Sciences
Siberian Branch
Institute for Biological
Problems of the Cryolithozone
41 Lenin Ave.
Yakutsk
Russia 677980
cherosov@mail.ru

N.S. Karpov
Russian Academy of Sciences
Siberian Branch
Institute for Biological
Problems of the Cryolithozone
41 Lenin Ave.
Yakutsk
Russia 677980

ISBN 978-90-481-3773-2 e-ISBN 978-90-481-3774-9
DOI 10.1007/978-90-481-3774-9
Springer Dordrecht Heidelberg London New York

Library of Congress Control Number: 2009943432

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Contents

1 Natural Conditions 1
A.P. Chevychelov and N.P. Bosikov

2 Flora of Yakutia: Composition and Ecological Structure 25
L.V. Kuznetsova, V.I. Zakharova, N.K. Sosina, E.G. Nikolin, E.I. Ivanova, E.V. Sofronova, L.N. Poryadina, L.G. Mikhalyova, I.I. Vasilyeva, P.A. Remigailo, V.A. Gabyshev, A.P. Ivanova, and L.I. Kopyrina

3 Vegetation of Yakutia: Elements of Ecology and Plant Sociology . . 143
A.P. Isaev, A.V. Protopopov, V.V. Protopopova, A.A. Egorova, P.A. Timofeyev, A.N. Nikolaev, I.F. Shurduk, L.P. Lytkina, N.B. Ermakov, N.V. Nikitina, A.P. Efimova, V.I. Zakharova, M.M. Cherosov, E.G. Nikolin, N.K. Sosina, E.I. Troeva, P.A. Gogoleva, L.V. Kuznetsova, B.N. Pestryakov, S.I. Mironova, and N.P. Sleptsova

4 Vegetation and Human Activity 261
M.M. Cherosov, A.P. Isaev, S.I. Mironova, L.P. Lytkina, L.D. Gavrilyeva, R.R. Sofronov, A.P. Arzhakova, N.V. Barashkova, I.A. Ivanov, I.F. Shurduk, A.P. Efimova, N.S. Karpov, P.A. Timofeyev, and L.V. Kuznetsova

5 Insect Impact on Vegetation 297
A.I. Averensky, I.I. Chikidov, and Yu.V. Ermakova

6 Structural and Functional Peculiarities of the Plants of Yakutia . . . 317
T.Ch. Maximov, A.V. Kononov, K.A. Petrov, and B.I. Ivanov

7 Nature Conservation Status and Its Prospects 357
B.Z. Borisov, M.M. Cherosov, I.A. Fedorov, P.S. Egorova, and P.A. Pavlova

Colour Plates 371

Index 389

Afterword

Instead of summarizing and concluding the information given in this book, we would like to emphasize on another topic: plans for the future and basic issues requiring further investigations. In other words, what to do next?

There are many interesting themes and issues that are waiting for specialists. The flora of Yakutia is still subject of study, especially the territories of South and South-East Yakutia bordering on the mountainous systems of South Siberia and the Far East. The recent 30 years of investigation have yielded over 400 species of higher vascular plants being first recorded in Yakutia, including its interior regions. And such hard-to-reach places as highlands, especially in the North-East, represent the real botanical “Klondike”; however, it would not be so easy to find a floristic “nugget”. This refers both to higher vascular plants and other plant groups.

Despite the low biological diversity (less than 2000 species of higher vascular plants), various territories are characterized by large numbers of endemic species. This is especially true for the north-eastern regions and some ranges in the North. The number of endemic and rare species of Yakutia is probably much higher than presently recorded.

The vegetation of Yakutia features the following interesting phenomena and issues:

– Xerophytization of the vegetation of Central Yakutia. There are still many places in the region to be explored by florists and geobotanists;
– The phytocoenoses of Yakutia are characterized by rather low α- and β-diversities. The reasons for this seem to be clear. However, the level of knowledge is not even throughout the territory of Yakutia due to varying approaches of community description.
– There are unique ecosystems in Yakutia that are more characteristic for more southern latitudes (steppe, tundra-steppe, etc.)
– There are patches of dark coniferous forests in the South, their elements penetrating northwards;
– North-West Yakutia features a specific interrelation between relief and vegetation, particularly where at low altitudes the flat territory is covered by alpine tundra communities;

- The interrelation between the tundra and valley species complexes in the river valley communities in South–East and South Yakutia is intriguing where arctic alpine and alpine species grow at all levels of the floodplain;
- In the Verkhoyansk Range, the link-up of the zonal forest and tundra vegetation at high altitudes needs careful research, when joint boundaries are obliterated.
- The gradual transition between the *Larix* forests and woodlands and *Pinus pumila* shrubberies in the highlands of North-East and South Yakutia is striking and a vegetation continuum is clearly seen. The syntaxonomical delineation of the continuum is of great interest.
- The largest botanical-geographical barrier in North-East Yakutia, the Verkhoyansk Range and other mountainous systems of North-East Russia as a whole, still warrants careful botanical and ecological investigation.

The typology of following vegetation is least studied in Yakutia:

- Bogs;
- Riparian and aquatic vegetation;
- Maritime vegetation;
- Psammophytic vegetation;
- Petrophytic vegetation including that of the slopes of mountain rivers;
- Alpine vegetation.

Other vegetation types are also waiting for more detailed investigation, since the size of Yakutia is very large and provides florists and geobotanists with work for a further hundreds of years.

We hope that foreign specialists, having become interested in the objects and ideas described in this book, will join us to study the Yakutian flora and vegetation in collaboration. For joint projects, please apply to any author:

Institute for biological problems of cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia

Introduction

The flora and vegetation of the Soviet Union have always attracted experts in botany from Western Europe and other countries. Up to the early twentieth century foreign explorers had a better opportunity to study the vegetation of the Russian Empire. After the Great October Socialist Revolution ideological obstacles hampered the development of scientific contacts and joint expeditions for several decades. Presently the situation has finally changed. Important international projects are implemented aiming to study the flora and vegetation of the former USSR countries: Kazakhstan, the Caucasus, Russian territories in the Altai, northern Russia, the Far East, etc. The study of the Yakutian flora and vegetation with international participation has a rather occasional character. However, such episodic cases pave the way for further comprehensive investigations to be conducted in collaboration with foreign colleagues.

Most botanical works on Yakutia have been published in Russia and in Russian. This significantly hampers the distribution of unique and interesting information abroad. And this is a common situation for many Russian regions. The authors of this monograph made an attempt to solve this problem in part.

Yakutia, with an area of over 3 million km^2, not only covers one fifth of all Russia. It also features peculiar vegetation growing on perennially frozen grounds, the so-called permafrost or cryolithozone that thaws only several metres deep and allows for a short growing season. How can plants survive under such extreme conditions? What are the adaptation mechanisms that allow them to withstand the cold winters with the lowest temperatures reaching sometimes minus 70°C? How can they successfully grow and propagate during the very short growing season under unfavourable hydrothermal conditions (up to + 30°C in July and 200 mm of annual precipitation)? These are the questions that every botanist would like to have the answers on.

Yakutia contains the vegetation of several natural zones, from the arctic deserts to the middle taiga with the elements of the southern taiga. Biodiversity, biogeography, ecology of flora and vegetation, these are the topics that are interesting to florists and plant sociologists, plant ecologists and ecophysiologists, as well as to other specialists in botany. We expect that this book will be able to fill a gap for foreign specialists on these important issues of nature investigation.

It may appear that the study of less than 2,000 higher vascular plant species and a description of their communities are not worth the trouble. However, after more than a century of investigations, the Yakutian vegetation is generally still an unexplored object, which gradually discloses its mysteries to persistent botanical explorers.

A reader who opens this book should realize that he holds in his hands the first generalization on the flora and vegetation of Yakutia based on long-term investigations by botanists mainly from the joint educational-research laboratory of floristics and phytocoenology of the Faculty of biology and geography (Ammosov Yakut State University) and the Institute for biological problems of the cryolithozone (Siberian Branch of the Russian Academy of Sciences). Most authors of the monograph have had an opportunity to explore various corners of this tremendous region lying in the core of the cryolithozone. They covered hundreds of kilometres by various means of transport: cars, helicopters, air planes, off-highway vehicles, and even on horseback, appreciating every rare opportunity to reach remote places. Many authors were the first to set foot in such lands reigned by wild animals and plants. And it is good that most of the territory of Yakutia still is wild nature.

There is no similar book in a Russian edition. It directly has come out in English, and it is very surprising and exciting that we could make it.

As will be clear from the contents of the book, the flora and vegetation of Yakutia are studied unevenly. This is explained by the history of interest in a certain object, and the presence of persons who initiated and developed research work on those objects.

The flora of Yakutia has been the object of study of many scientists. In the beginning of the twentieth century the Yakutian flora was described by academician V.L. Komarov. However, its structure and principles of spatial organization were revealed in the middle of the twentieth century by Mikhail Nikolaevich Karavaev. He worked at the Yakut State University for a certain period, though most of his life he headed the Herbarium of the M.V. Lomonosov Moscow State University.

Most of Yakutia is covered by forest. The study of forest communities has always been a constituent part of the research activity of the Institute for Biological Problems of the Cryolithozone, Siberian Branch of the Russian Academy of Sciences, as well as of the Yakut State University. Igor Petrovich Scherbakov has long headed the forest school of Yakutia. He initiated the investigation of forests on frozen grounds, which was continued by his followers.

The specialist in meadows, plant ecologist, botanist-geographer Konon Evseyevich Kononov was the founder of the Group of phytosociology at the Faculty of Biology and Geography (Yakut State University). The aim of the Group was to study the syntaxonomy and map the herbaceous vegetation. The main achievements of K. Kononov's research activities were to reveal the main principles of the meadow and steppe vegetation structure and the classification of herb vegetation using the Braun-Blanquet approach. He and his followers and colleagues were the first who familiarized the foreign specialists with the main syntaxa of the Yakutian meadow and steppe vegetation.

The famous geobotanist Valdimir Nikolaevich Andreyev came to Yakutia from Leningrad at a mature age. He studied the tundra communities and trained his followers who still study the flora and vegetation of Yakutia nowadays. His ideas on the principles of the distribution of the tundra vegetation, on the biology and ecology of tundra plants, have determined the general lines of investigation of the tundra flora and vegetation for many years. His organizational abilities and status as a leading botanist of Yakutia have allowed the publication of a number of summarizing works on the flora and vegetation of Yakutia.

We authors would never write this monograph without the works of their predecessors in the twentieth century. The list of those specialists is not limited to the abovementioned recognized leaders of Yakutian botany. Most of our elder colleagues are already no longer with us. However, they brought us up as specialists, and passed on their knowledge, experience and persistency in overcoming obstacles to study the flora and vegetation of Yakutia. We authors express their gratitude and dedicate this book to our teachers.

We authors also acknowledge everyone who took part in the preparation of the monograph, appreciate the patience of the scientific editor and management of the Publishing House. Without all this, the book would never have been published.

Team of authors

Contributors

A.P. Arzhakovan Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, BNW-07@yandex.ru

A.I. Averensky Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, aaver37@yandex.ru

N.V. Barashkova Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, BNW-07@yandex.ru

B.Z. Borisov Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, bzborisov@mail.ru

N.P. Bosikov Institute of permafrost, 36 Merzlotnaya Str., Yakutsk, 677010, Russia, bosik@mpi.ysn.ru

M.M. Cherosov Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, cherosov@mail.ru

A.P. Chevychelov Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, chev.soil@list.ru

I.I. Chikidov Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, chikidov@rambler.ru

A.P. Efimova Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, aytaef@yandex.ru

A.A. Egorova Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, eang@mail.ru

P.S. Egorova Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, yakutgard@mail.ru

N.B. Ermakov Central Siberian Botany Garden, 101, Zolotodolinskaya Str., 630090 Novosibirsk, Russia, brunnera@mail.ru

Y.V. Ermakova Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, yermakova68@mail.ru

I.A. Fedorov Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, yakutgard@mail.ru

V.A. Gabyshev Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, v.a.gabyshev@ibpc.ysn.ru

L.D. Gavrilyeva Institute for applied ecology of the North, 5 Kalandarishvili Str., Yakutsk, 677025, Russia, adoxa@mail.ru

P.A. Gogoleva Yakut State University, Faculty of Biology and Geography, Room 456, 48 Kulakovsky Str., Yakutsk, 677000, Russia, sedum@mail.ru

A.P. Isaev Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, forest_forest@ibpc.ysn.ru

I.A. Ivanov Kv. 26, Kirov Str., Yakutsk, 677007, Russia, anere.35@mail.ru

B.I. Ivanov Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, bio@ibpc.ysn.ru

E.I. Ivanova Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, e.i.ivanova@ibpc.ysn.ru

A.P. Ivanova Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, a.p.ivanova@rambler.ru

N.S. Karpov Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, bio@ibpc.ysn.ru

A.V. Kononov Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, a_v_kononov@ibpc.ysn.ru

L.I. Kopyrina Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, l.i.kopyrina@mail.ru

L.V. Kuznetsova Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, kuznetsova90@mail.ru

L.P. Lytkina Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, forest_forest@ibpc.ysn.ru

T.Ch. Maximov Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, t.c.maximov@ibpc.ysn.ru

L.G. Mikhalyova Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, lgmikhalova@rambler.ru

S.I. Mironova Institute for applied ecology of the North 5 Kalandarishvili Str., Yakutsk, 677025, Russia, s.i.mironova@ipes.ysn.ru

N.V. Nikitina Yakut State Academy of Agriculture, Olyokminsk Branch, 58 Gagarin Str., Olyokminsk, 678100, Russia, nadezhda_nikitin@mail.ru

A.N. Nikolaev Institute of permafrost, 36 Merzlotnaya Str., Yakutsk, 677010, Russia, yktnan@mpi.ysn.ru

E.G. Nikolin Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, enikolin@yandex.ru

P.A. Pavlova Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, yakutgard@mail.ru

B.N. Pestryakov Yakut State University, Faculty of Biology and Geography, Room 240, 48 Kulakovsky Str., Yakutsk, 677000, Russia, pbn_bot@mail.ru

K.A. Petrov Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, kap_75@bk.ru

L.N. Poryadina Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, lnporyadina@rambler.ru

A.V. Protopopov Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, a.protopopov@mail.ru

V.V. Protopopova Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, a.protopopov@mail.ru

P.A. Remigailo Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, p.a.remigailo@ibpc.ysn.ru

I.F. Shurduk Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, forest_forest@ibpc.ysn.ru

N.P. Sleptsova Yakut State University, Faculty of Biology and Geography, Room 240, 48 Kulakovsky Str., Yakutsk, 677000, Russia, endyps@rambler.ru

R.R. Sofronov Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, r.r.sofronov@ibpc.ysn.ru

E.V. Sofronova Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, e.v.sofronova@ibpc.ysn.ru

N.K. Sosina Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, n.k.sosina@ibpc.ysn.ru

P.A. Timofeyev Yakut State University, Faculty of Biology and Geography, Room 240, 48 Kulakovsky Str., Yakutsk, 677000, Russia, timpa@inbox.ru

E.I. Troeva Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, etroeva@mail.ru

I.I. Vasilyeva Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, l.i.kopyrina@mail.ru

V.I. Zakharova Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia, e.i.ivanova@ibpc.ysn.ru

Chapter 1
Natural Conditions

A.P. Chevychelov and N.P. Bosikov

The Republic of Sakha (Yakutia) is situated in the north-east of Siberia. The northernmost point of continental Yakutia lies on the Nordwick cape (74°N), while the northernmost island point is situated in the north of the Henrietta Islands (77°N). The southernmost point is on the Stanovoy Range (55° 30′ N) nearly conforming to Moscow's latitude. The westernmost and easternmost points lie on 105° 00′E and 165° E respectively. Thus, the territory of Yakutia stretches for 2000 km from the north to the south, and 2500 km from the west to the east.

The area of Yakutia (3 103 200 km^2) makes up one-fifth of the Russian Federation's territory. The Republic is larger than France, Austria, Germany, Italy, Switzerland, England, Finland and Greece put together. Some islands of the Arctic Ocean, including the Novosibirskie Islands, belong to the Republic. Over 40% of Yakutia's territory is beyond the Polar Circle. There are three time zones in its area. The capital of the Republic of Sakha (Yakutia), Yakutsk city, is 8468 km away from Moscow.

In the north, Yakutia borders the Laptev and East-Siberian Seas which are part of the Arctic Ocean. The coastline is approximately 4000 km (Mostakhov et al. 1980; Matveyev et al. 1989).

1.1 Geomorphology and Relief

The territory of Yakutia is divided into three large zones: western, eastern and southern Yakutia (Fig. 1.1). According to the natural zonation of the former USSR, the western zone of Yakutia belongs physiographically to the "Middle Siberian plateau" (Korzhuev 1974). The southern part is part of the Aldan-Okhotsk physiographic zone, and the eastern part of the Republic is partly represented by the East-Siberian mountainous country and by vast lowlands of North-eastern Yakutia.

A.P. Chevychelov (✉)
Institute for biological problems of the cryolithozone, 41 Lenin Ave., Yakutsk, 677980, Russia
e-mail: chev.soil@list.ru

E.I. Troeva et al. (eds.), *The Far North: Plant Biodiversity and Ecology of Yakutia*,
Plant and Vegetation 3, DOI 10.1007/978-90-481-3774-9_1,

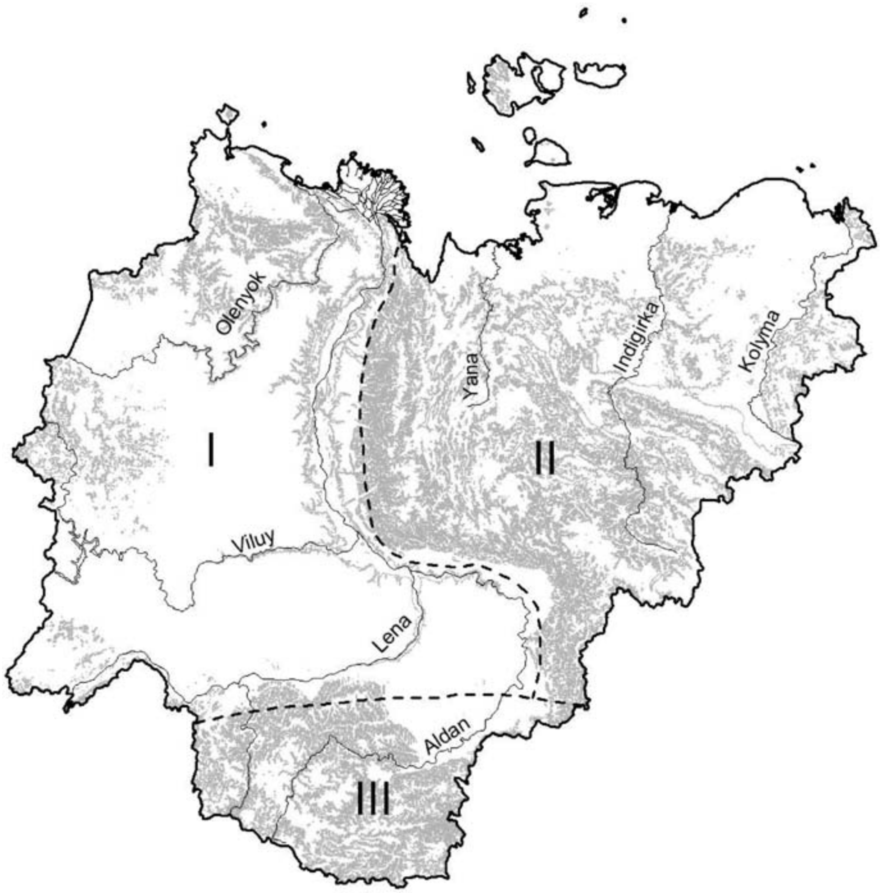

Fig. 1.1 Physiographical zones of Yakutia (by Korzhuev (1965)) I – West Yakutia, II – East Yakutia, III – South Yakutia

The last two zones are characterized by a complicated latitudinal and altitudinal zonation (Fig. 1.2).

Physiographic zonation (Fig. 1.1) is based on a set of all natural elements though the role of a key element is very important. Thus, key elements for West Yakutia, characterized by plains and plateau, are soil and vegetation, while relief is the major factor for South Yakutia. Relief has an influence upon vegetation and soil patterns, climate and other natural elements and is reflected in vertical (elevational) zonation (Korzhuev 1974).

Geomorphologically the territory of Yakutia consists of two large areas: the plateau and the folded areas. The latter, represented by mountains and high tablelands, covers two thirds of the territory and is largely centered in the north-east, east and south-east of the republic. Tablelands and plateaus are located in West

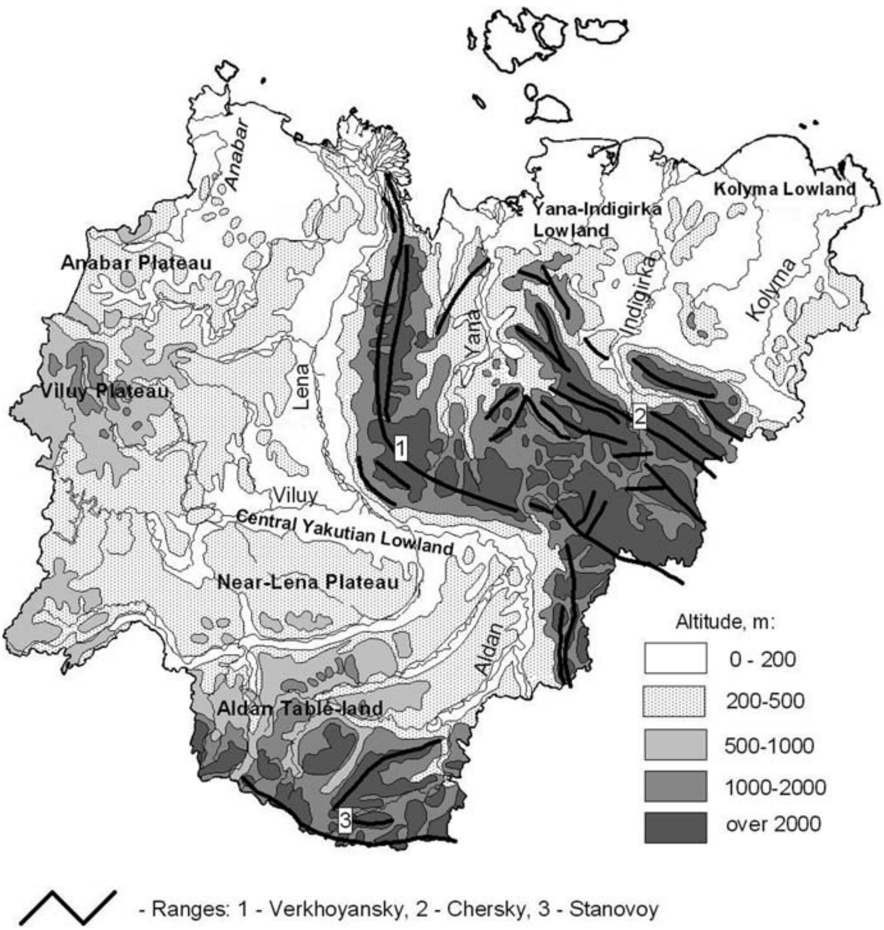

Fig. 1.2 Orographic scheme of Yakutia (by Korzhuev (1965))

Yakutia, while the northern and central regions are characterized by vast depressions (Korzhuev 1965) including the largest lowlands in Yakutia, the Anabar-Lena and Central Yakutian Lowlands, which lie at altitudes of 50–100 and 60–200 m, respectively. The Central Yakutian Lowland is a colossal depression surrounded nearly from all sides by mountainous systems and high tablelands. It is open only in the north towards the Lena River's lower reaches. The Lena and its major tributaries (the Aldan and Viluy Rivers) divide the depression into the Lena-Viluy and Lena-Aldan parts. These rivers have washed away loose sediments off the plain and formed wide valleys consisting of several terraces of various widths.

The main plateaus of West Yakutia are Lena-Aldan, Anabar-Olenyok, and Olenyok-Viluy.

Most of South Yakutia is situated in the Aldan tableland with an average altitude of 800–1100 m. Eastwards, it merges into the Uchur-Maya upland region and the Aldan-Uchur Range, which reaches as high as 2246 m. The southernmost area of the Aldan tableland borders outlying areas of the Stanovoy Range, the height of which reaches 2000 m in the west and 2412 m in the east.

East Yakutia has an even more complicated surface structure, with mountainous country consisting of vast tablelands, upland regions and mountain ranges. The largest of these are the Verkhoyansk mountain chains (2250–2959 m) located along the Lena and Aldan Rivers. To the east of the Verkhoyansk Range, the Chersky Range is situated, featuring the highest point of the north-east – the Pobeda (Victory) mountain (3147 m). Between the Verkhoyansk and Chersky Ranges vast tablelands are situated: Yana, Oymyakon with the Oymyakon depression in the Upper Indigirka, and Nera. The Yana-Indigirka and Kolyma Lowlands cover the north, while the Yukagir tableland lies in the east-north-east.

1.2 Hydrography

Yakutia borders the Laptev and East-Siberian Seas (Fig. 1.1), the shallowest seas of the Arctic Ocean. Their floor represents a continental terrace. The coastline is quite dented forming numerous bays, straits, peninsulas, and capes. The largest bays are the Anabar, Olenyok and Yana Bays. The Yakutian seas are the coldest in the Arctic. Winter temperatures of the water under ice cover range from 0.2° in the river mouths to +2° at the northern borders of the seas. Summer temperatures of the surface water in bays reach +7° to +10°, whereas in the open sea it is only +1° to +3°C. The Laptev and East-Siberian Seas are the iciest in the Northern Hemisphere. For 9–10 months, they stay covered with ice as thick as 1.5–2 m. The severe nature of the Arctic creates unfavourable conditions for the flora and fauna of the seas bordering Yakutia (Mostakhov et al. 1980).

The river network of Yakutia is rather complicated and belongs to the Laptev and East-Siberian Seas basins. Besides the large rivers, a huge number (0.5 million) of small rivers and streams with a total length of over 1.5 million km drain the territory of Yakutia. The Lena River has the largest basin (65% of the territory) and its major tributaries are the Viluy and Aldan Rivers. Other large rivers are the Anabar, Olenyok and Yana Rivers flowing into the Laptev Sea, and the Indigirka and Kolyma Rivers flowing into the East-Siberian Sea. The Aldan and Indigirka Rivers' networks are the most complicated ones while that of the Viluy is poorly developed. Yakutian rivers are mountainous in their upstream parts, transitional mountainous-lowland in their midstream parts, and typical lowland in their down stream parts. As a rule, almost all large rivers form vast deltas. Precipitation (both snow and rain) plays a major role in river feeding. Discharge is uneven over the year – during the warm period melt waters, rain and other sources provide 90–100% of the annual volume, whereas winter drainage does not exceed 10% of the year's total. The greatest water discharge is usually observed in May–June, during spring tides of the rivers.

Maximum water discharge of the mountainous rivers in the southern and north-eastern regions of the republic is often during summer high water (Mozolevskaya 1973).

River water temperature reaches maximum values in July-early August (25–28°). River freezing-over in Yakutia lasts 180–200 days. Spring flood starts during the first ten days of May in the southern regions and in late May in the North. Spring tides are often accompanied by huge ice blockades, yielding a significant increase in water levels which, in turn, leads to floods.

In Central Yakutia rivers get free of ice in the second half of May and freeze in late October – early November (small rivers freeze in the first half of October) (Mozolevskaya 1973).

Lakes are also common in Yakutia, being mostly of thermokarst and flood-plain origin. In the Lena-Viluy Lowland lakes make up 15–30% of the territory. Nidzhily, the largest lake in Yakutia (119 km^2), is situated there. Some lakes are as deep as 100 m or even more, though the average depth reaches only 3–10 m.

River drainage rates in the Viluy River basin are much reduced due to water retention by numerous lake depressions in some parts of that region. The same phenomenon is observed in the Lena-Aldan Interfluve, which is known for the large number of lakes that are not drained. Such lakes accumulate moisture and evaporate it intensively during hot periods. As a result, many such lakes gradually dry up.

1.3 Climate

In most of the territory of Yakutia, except for its coastline and the highland region in the South, the climate is strongly continental with very low winter and very high summer temperatures, insignificant nebulosity and relatively mild winds, especially in winter.

A major pressure phenomenon is the establishment and growth of the Asian anticyclone system at the very beginning of the winter. This determines the thermal and wind characteristics of the winter period. The high pressure produces extremely steady air with very low surface temperatures, strong surface inversions and low humidity.

The strong continentality and severity of the climate is felt even more rigorous in some parts of Yakutia due to their location in mountain valleys or enclosed tablelands where, in wintertime, cold, heavier air masses stream down from watershed plateaus. Weak circulation and ground radiation make the air stagnant and even colder (Mozolevskaya 1973).

Figures 1.3 and 1.4 depict the standard climate diagrams following the Walter and Lieth (1960) method. The tops of each diagrams list the name of the climate station, its altitude above sea level (m), its average annual temperature (°C), and its average annual precipitation (mm).The diagrams show curves for the average monthly temperatures (1 scale unit = 10°C) and average monthly rainfall (1 scale unit = 20 mm). Months of the year are arranged along the horizontal axis, which

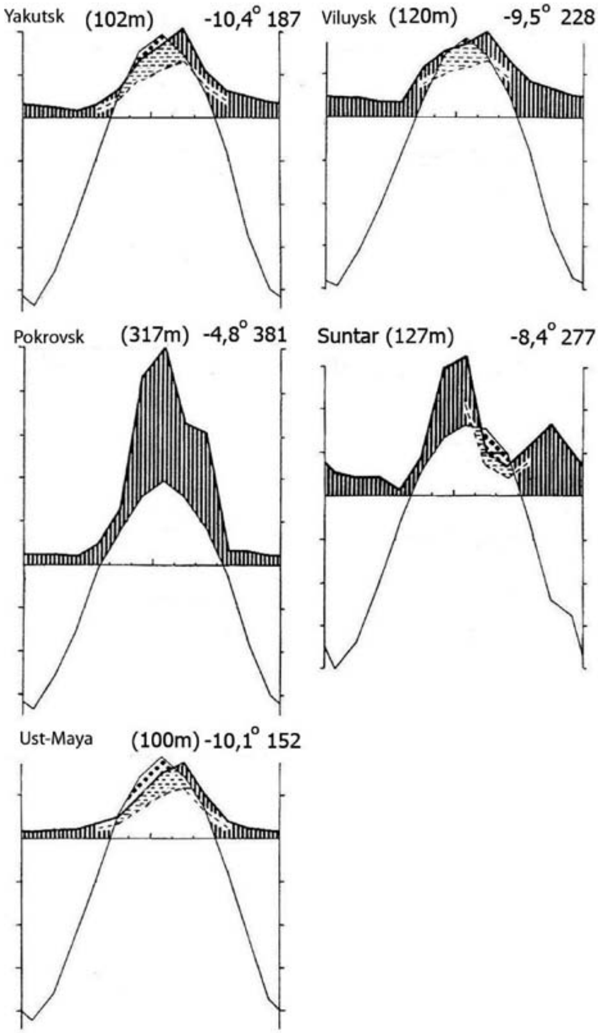

Fig. 1.3 The standard climate diagrams for Central – South Yakutia

represents 0°C and 0 mm. When the rainfall curve is above the temperature curve the period is considered moist (vertically hatched); when the temperature curve is above the rainfall curve the period is considered dry (dotted). Some climate diagrams show apart from the standard scaling of 10°C against 20 mm of rain an additional monthly rainfall curve for the months of the summer season at a scaling of 10°C against 30 mm of rainfall.

Most of the territory experiences its lowest air temperatures in January, rarely in December or February. In coastal areas, January and February temperatures are almost equal, while on the islands February is the coldest month. From November

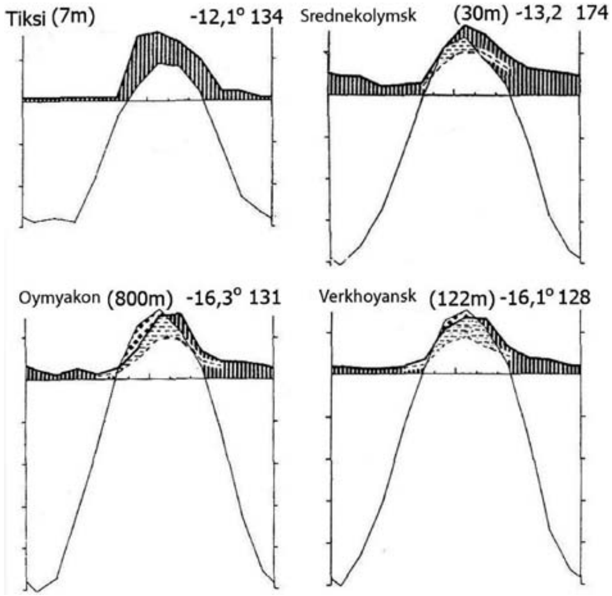

Fig. 1.4 The standard climate diagrams for North Yakutia

through February, the lowest temperatures are observed in the Oymyakon depression and Yana intermountain trough. Long term winter average air temperatures in Oymyakon and Verkhoyansk are –50°C and –49°C, respectively. Towards the coastal area, the temperature rises to –35°C to –30°C, and to –30°C to –27°C on the islands. Strong surface air inversion (rise in temperature at higher elevations) is a quite ordinary phenomenon during the cold period. They are so constant and intensive, that they have an effect on the mean annual average perennial temperature values at meteorological stations situated in mountains.

Some days, 60° below zero can be observed almost all over the territory. Extremely low temperatures have been recorded in the Oymyakon depression and Yana intermountain trough: –71°C in Oymyakon and –68°C in Verkhoyansk. Minimal temperatures in the South and South-West may reach –58°C to –62°C, and in Central Yakutia –66°C. In coastal areas and on islands, the lowest recorded temperatures are –46°C and –52°C. At a short distance from the shoreline as well as in deep bays, minimal values are considerably less severe.

The duration of the period with temperatures of –50°C or lower varies widely: from 10 h on the Arctic coast to 900 h within the Yana-Indigirka tableland. Yakutia has no analogues both in minimal temperature values and the duration of the period with extremely low temperatures in the Northern Hemisphere (Mostakhov et al. 1980).

A distinct feature of the warm period is the quick rise of the average daily temperatures in spring and their quick drop in autumn. July is the warmest month. The highest temperatures in Yakutia between May to August are observed in the central region. The average July temperature in the central, southern, and south-western parts of the republic is +17 to +19°C, while North of the Viluy River it ranges from +12 to +15°C. Lowest July temperatures (+2 to +5°C) are recorded in coastal areas and on the islands. In highland regions, temperature distributions depend on altitude, relief, and other microclimatic peculiarities. In most of the lowlands maximum temperatures may reach +34 to +38°C, in the coastal areas +29 to +32°C, and on the islands +18 to +24°C.

Characteristic of the thermal conditions of Yakutia are the significant annual amplitudes. Differences between temperatures of the warmest and coldest months and differences between absolute minimum and maximum values in the interior are the world's greatest. Thus, the amplitude of the average monthly temperature varies from 53.0 in Tommot to 61.8 in Ust-Moma with a maximum value of 64.5 in Oymyakon. Amplitudes of absolute minimum and maximum temperatures at those localities reach 99, 102, and 104°C, respectively. Coastal areas and islands are characterized by smaller temperature amplitudes due to their mild winters and cool summers (Mozolevskaya 1973). Sums of temperatures above freezing point vary over a wide range from the coastline towards the lowlands (Table 1.1).

Warm periods with an average daily temperature above zero, in the agricultural zone of the republic, last 150–165 days from the end of April-early May to late September.

The transition to an average daily air temperature above 10°C (which means the start of plant growth) occurs in early July in the tundra, in the first decade of June in the West, and in late May in the central and south-western regions. Back transitions start in the first decade of August in the tundra, in the second and third decades of August in West Yakutia, and in early September in the central and south-western regions (Izyumenko 1966).

The average duration of the period with temperatures above 10°C is 0–50 days in the tundra, 65–90 days in the West, and 90–100 days in Central and South-West Yakutia.

The duration of the frost-free period varies significantly due to the sheer size of the republic and its complicated relief. The longest frost-free period (95–100 days) is recorded in the Middle Lena River valley. In the tundra such period hardly lasts

Table 1.1 Distribution of sums of positive average daily temperatures in Yakutia in relatively flat areas (°C)

	Sums of temperatures during periods with temperature above			
Regions	0°	5°	10°	15°
Sea islands	50–300	0		
Coastline	300–500	0–300	0	
Tundra	600–900	500–800	0–500	0
Western regions	1200–1600	1100–1500	800–1200	0–700
Central and south-western regions	1700–1900	1600–1800	1400–1600	800–1200

two months. Sometimes frost may occur all summer long. In highlands, the frost-free period also varies in length. In some years, cold-air surges from the North cause advective radiation frost all over the territory all summer long.

Solar radiation income is very significant in summer thanks to the long duration of daylight and high radiation intensity. The polar day occurs in summer beyond 67°N, while in the rest of the territory there are 18–20 h of day light. Radiation sums for the three summer months in Yakutia total 1590 – 1925 MJ/m^2, making up approx. 41–49% of the annual income (Mozolevskaya 1973).

Winter is the clearest season of the year with least nebulosity in February and March. Summer and autumn are characterized by relatively high nebulosity.

The annual precipitation amounts for most of the territory to 200–250 mm, and 350–500 mm in the South and South-West. Precipitation falls unevenly during the year: 15–20% of the total amount occurs during the cold period (November through March), and 4–5 times more (75–80%) during the warm period (April through October). Coastal areas, islands, the Yana and Oymyakon table-lands, the Verkhoyansk and Moma-Selennyakh depressions, as well as the Central Yakutian Lowland are characterized by extremely low amounts of precipitation (150–250 mm per year). In foothills and highland regions, precipitation amounts to 400 mm in the Olyokma and Chara watersheds, the Aldan tableland, and up to 500–700 mm on western slopes of the Aldan-Uchur Range and ridges of the Verkhoyansk Range. Obviously, in the mountains a significant part of the precipitation runs off. During the vegetation period, June is the hardest month for plants when lack of precipitation is observed all over the territory except for its southern and north-western parts. July and August have the highest precipitation values (Izyumenko 1968a).

In most of Yakutia snow cover lasts 225–250 days a year. The shortest period (220–225 days) is observed in the Viluy, Aldan and Middle Lena River valleys, while in coastal areas and on the islands snow cover is longest (260–295 days). Depth of snow cover is insignificant (especially in the North) due to the prevalence of anticyclonic circulation in winter. Deepest snow cover (40–60 cm) is observed in the Upper Aldan River basin, the Kolyma River valley, and in some highland regions. In mountains, snow depth may vary depending on altitude and prevailing wind direction. Snow starts melting in late April, though active solar radiation causes snow evaporating already in March (Izyumenko 1968a).

Being determined by peculiarities in the atmospheric circulation, wind characteristics (direction and speed) vary between winter and summer periods. Winter (September through May) is characterized by prevalence of southern, south-western, and western winds in most of the republic, while in the South-East northern and north-western directions predominate. In summer, winds blow mostly from the North, North-East, North-West and West, and for South-East Yakutia southern winds prevail. Wind speed values are insignificant. In most of the territory, mildest winds (1–2 m/sec) are recorded in January–February. In the enclosed valleys and lowlands (depressions) (Ust-Moma, Oymyakon, Verkhoyansk) wind speed does not exceed 0.2–0.4 m/sec. Increase in cyclonic activity in summer yields wind speeds of up to 5 m/sec. Strong winds are quite uncommon for most parts of the republic (Izyumenko 1968b).

Table 1.2 Zonal-subzonal change in climate in Yakutia (Izyumenko 1966, 1968a, b)

Meteostations	True altitude (m)	Climatic indices* Σ t>10°C	C_h	C_c	Climate description
North Yakutia, arctic tundra					
Preobrazhenie Isl.	6	0	1.9	138	Arctic, cryogenic, moderately continental,
Dunay Isl.	5	0	2.6	-	excessively humid
North Yakutia, subarctic tundra					
Ust-Olenyok	11	0	1.0	176	Subarctic, long periods of frost, moderately to strongly continental,
Kyusyur	35	576	0.8	220	semi-humid
North Yakutia, northern taiga					
Olenyok	127	846	0.6	246	Cold, cryogenic, very to
Jarjan	50	950	0.7	238	strongly continental,
Zhigansk	53	1090	0.6	256	semi-arid
Central Yakutia, middle taiga					
Viluysk	110	1421	0.4	251	Moderately cold, long
Yakutsk	99	1565	0.3	302	periods of frost, strongly to
Ust-Maya	169	1457	0.4	305	extremely continental, very
Isit	117	1503	0.4	268	arid
South Yakutia, middle and upper taiga					
Tommot	283	1370	1.0	272	Moderately cold to cold,
Aldan	676	1281	1.3	231	frosty, very to strongly
Emeldzhak	951	1062	1.9	224	continental, humid to
Chulman	671	1158	1.3	279	excessively humid

*Σ t>10°C sum of air temperatures above 10°C;, C_h humidity, C_c continentality

Climatic shifts with respect to geographic zonation (i.e. latitudinal and altitudinal aspects) also should be given consideration (Table 1.2). We analyze this here based on integral climatic indices (sum of temperatures above 10°C, precipitation-evaporation ratio (C_h), continentality (C_c)). Low thermal resources in the Arctic tundra cause low evaporation of precipitation, and thus result in high humidity under the conditions of moderate continentality as observed along the coastline of the northern seas.

In the subarctic tundra an increase in the thermal factor reduces the humidity (C_h = 0.8–1.0) while the continentality hardly rises. In the northern taiga, farther inland, the thermal factor increases (Σ t > 10°C = 846–1090°). This means that the continentality increases (C_c = 238–256), and the humidity slightly decreases (C_h = 0.6–0.7). In the middle taiga of Central Yakutia the highest values for the thermal factor are recorded, with the sum of temperatures reaching 1421–1565° while continentality (C_c = 302–305) and aridity are severest (C_h = 0.3–0.4).

Towards the South of Yakutia, mountainous relief makes the climatic indices more complex. There, at higher altitudes (compared to Central Yakutia) in mountain taiga, the thermal factor decreases somewhat (Σ t > 10°C = 1062–1370°), which cause the humidity to rise significantly (C_h = 1.0–1.9) while the continentality decreases. It is important to note that depressions and hollows have a profound effect on the abovementioned climatic indices, yielding the well-known phenomenon of thermoaridity in the bottom lands in contrast to surrounding watershed area. Thus, in the Chulman depression that runs into the Aldan upland as far as 500 m, a reduction of 100 m in altitude is accompanied by an increase in continentality (+18) and in sum of temperatures (+43°), and a decrease in annual precipitation (–32 mm).

1.4 Permafrost

Permafrost is a basic factor greatly influencing the distribution and functioning of ecosystems, and vegetation in particular (Nekrasov 1984).

The whole territory of Yakutia lies in the zone of perennially frozen soils. The permafrost stratum varies widely in depth within Yakutia. Thus, on above-floodplain terraces, it is as thick as 300–400 m, while in the upper reaches of the Markha River (West Yakutia, south of the Polar Circle) it reaches 1500 m. This is the maximum thickness recorded worldwide. The average annual temperature of perennially frozen grounds at a depth of 15–20 m fluctuates from –1° to –2°C (SW Yakutia) to –10° to –12°C (high watersheds in mountains) (Mostakhov et al. 1980).

The continuous permafrost zone alternates with patches of non-frozen grounds, the so-called *talik*. In Southern Yakutia (the Lena-Aldan and the near-Lena plateaus, as well as upper regions of the Yakokit and Seligar River basins), taliks occupy up to 50% of the area and are concentrated on dry, flat watersheds, under river beds which do not freeze through in winter, under deep lakes, and near permanent sources of underground water. Absence of permafrost is explained from the specific composition of carbonate rocks, their waterproof properties and extensive karst processes, as well as by good infiltration of precipitation, because the average annual temperature of those rocks is as high as 1–2°C due to convective heat transfer by infiltrating precipitation (Petrova 1971).

Firmly frozen, ice-bound strata represent waterproof horizons for precipitation and facilitate to some extent soil wetting by oozing out ground moisture during seasonal periods of thawing (Mozolevskaya 1973).

Ice, as a constituent part of the perennially frozen grounds, determines their heat-transfer and mechanical properties. Ice is a unique solid substance being the lightest rock-forming mineral with the lowest melting temperature. Due to these characteristics, ice is located in the near-surface layers of the earth's crust. Ground, constitutional ice is most widespread. It includes the following types: ice-cement, segregation (migration) ice, and injection (intrusive) ice.

Ice-cement is formed from water freezing in between particles of fine-grained rocks without affecting the spatial position of those particles. Due to very small ice crystals, invisible to the naked eye, the frozen rock represents a monolithic, firmly cemented mass.

Segregation ice is formed in moist, loamy, micrograined soils under condition of water inflow (migration) to the "freezing front". Moist soil freezing is always accompanied by water inflow from the deeper horizons resulting in the development of ice lenses.

Injection ice, like segregation ice, is also formed from underground water, but of larger volumes and under significant pressure. Injection ice represents extensive layers and lenses several tens of meters thick and several hundreds of meters long, very often yielding large frost boils on the surface called *bulgunnyakh* in Siberia and *pingo* in Alaska and Canada.

Fissure ice (wedge or vein ice) is the result of water freezing in cracks of rocks as well as in holes and cavities common in carbonate landscapes. *Recurrent-fissure ice* is a very common phenomenon in the lowlands of Northern and Central Yakutia. Its formation process is typical of land surfaces cracking during severely cold weather. Such cracks are called frost fractures, and the whole micro- or nanorelief of the surface is called polygonally-fractured. The ice veins have a wedge, columnar or irregular shape in cross-section (Fig. 1.5).

Various natural processes as well as human activity (such as fires, deforestation, agriculture, use of heavy machinery) induce thermokarst processes. This phenomenon of permafrost thawing leads to land surface destruction resulting in the formation of unique landscapes. The following are the most distinct types of such landscapes.

Bulgunnyakh (Pingo) is a domelike hill with an ice core (hydrolaccolith). They occur one by one in depressions of flat tundra, forest-tundra and *alases* (see below) of Central Yakutia. They vary in height from 1 to 30–40 m and continue to grow for up to 1000 years. Landscapes with pingos are sometimes considered as a special type of hillocky tundra.

Baidjarakh complex (*earth mounds, "burial mounds")* represents muddy-peaty, sometimes muddy-loamy or sandy cones of 3–4 m (up to 12 m) high, 3–15 m wide and up to 20 m long (Fig. 1.6). The frost boil landscape is the result of thawing and freezing of recurrent-fissure ice which forms a grid with polygonal cells. The young

Fig. 1.5 Exposed recurrent-fissure ice veins on eroded slopes of a river bank in the northern taiga zone

Fig. 1.6 Baidjarakh complex on the slopes of a mature alas

baidjarakhs have a regular, clear shape of an up-side-down bowl, while the old ones are eroded by water and wind, and are covered with vegetation. At the same time, they retain a round or quadrangular shape at their bases. This phenomenon is very common in Central and North Yakutia on above-floodplain terraces, lakes or coastal depressions, and they are grouped in parallel, staggered rows. In the tundra zone the baidjarakhs may cover large areas (up to thousands of hectares).

Alas represents a shallow depression, formed by thermokarst, with meadow or steppe vegetation, in the taiga in Central Yakutia (Fig. 1.6). The process of alas formation runs through several stages. Solar radiation induces thawing of buried ice in open spots in the taiga and this leads to the formation of a baidjarakh complex. Gradually, the soil that continues to thaw forms a depression, in which melt water forms a pond or a lake. The lake slowly dries out, giving space to herbaceous vegetation. Later, a new ice lens may form underground, and a pingo may appear in the middle of the alas. There is an important difference between alases and other thermokarst depressions met in Northern Yakutia. The lakes and lake depressions in the lowlands of North-Eastern Siberia develop under conditions of excessive moisture. These lakes are full of water and can be drained only artificially. In Central Yakutia, due to the arid climate, an alas lake desiccates after the resources of underground ice have been depleted, and allows vegetation to grow. (We shall discuss the alas vegetation complex in Chapter 3). Thus, the arid climate is the only factor which leads to the formation of these peculiar landscapes. The particular process of alas evolution, and its distinctive soil and vegetation complex make it worthwhile to treat them as a special alas-type of a landscape in Central Yakutia (Bosikov 1993). Alases represent high-quality hayfields and pastures for livestock and horses.

*Naled (*Icing*)* is very common in Eastern Siberia and the Far East. It develops under the conditions of a severe climate, when deeply frozen ground and ice cover on rivers form a kind of pipe or tunnel for river water. In some places this water is forced to the surface and immediately becomes frozen. This is called a river naled.

Sometimes, this phenomenon occurs far from river valleys caused by underground waters oozing and freezing on the surface (ground naled).

In upland regions thawing of permafrost induces rock slides and solifluction processes on gentle slopes, when thawed, wet soils slide on the perennially frozen substrate.

The perennially frozen grounds are overlain by a soil stratum which thaws in summer (the active layer). In most of Central and North-Western Yakutia, the depth of seasonal thawing varies from dozens of cm to 2–3 m depending on the geographical location, relief, vegetation pattern, soil composition, etc. In Central Yakutia and the western near-Lena regions, soils thaw as deep as 1–4 m. Such values are characteristic for forested watershed areas, whereas waterlogged territories show less deep thawing. In Northern Yakutia (tundra and forest-tundra zones), the depth of the thawing layer is 0.3–0.8 m. In the south and south-west regions with higher amounts of precipitation, soils thaw as deep as 2.5–4.0 m (Mozolevskaya 1973).

Soils start thawing right after the snow cover has melted, and they freeze in autumn as soon as the average daily air temperature comes below 0°C. The freezing process proceeds simultaneously in a top-down and a bottom-top direction, and in January both frozen layers meet. Thawing depth values are not constant and depend on the meteorological features of a year.

Based on the thickness of the seasonally thawed soils, Nekrasov (1984) divides the territory of Yakutia into 5 zones (Table 1.3 and Fig. 1.7) with thaw-layer thickness of sandy loams within 0.5–3.0 m, and of loams within 0.3–1.8 m. The scheme clearly illustrates that the soils of the arctic and subarctic lowland tundra, as well as those of highland areas, i.e. chains of mountain ranges in North-East Yakutia (Verkhoyansk, Chersky, Momsky), thaw to relatively shallow depths (sands 0.5–1.5 m, sandy loams 0.3–1.0 m), while the thawing depths of soils of the strongly thermo-arid Central Yakutian Lowland are much deeper (sands 2.2–3.0 m, sandy loams 1.4–1.8 m).

Table 1.3 Thawing depths in Yakutia (in m) (see text for explanation)

	Zone	I	II	III	IV	V
Depth (m)	Sandy	0.5–1.0	1.0–1.5	1.5–2.0	1.9–2.5	2.2–3.0
	Loamy	0.3–0.7	0.7–1.0	1.0–1.3	1.2–1.6	1.4–1.8

1.5 Soils

Due to the huge area of Yakutia and the greatly different conditions of soil formation, such as landscape, climatic, lithological and geochemical peculiarities, the soil cover is very diverse and comprises a wide range of zonal, azonal, and intrazonal soil types.

Geographically, most of Yakutia (38%) belongs to the middle-taiga subzone of the taiga-cryolithozone region of the boreal belt of Eastern Siberia. 31.5% falls

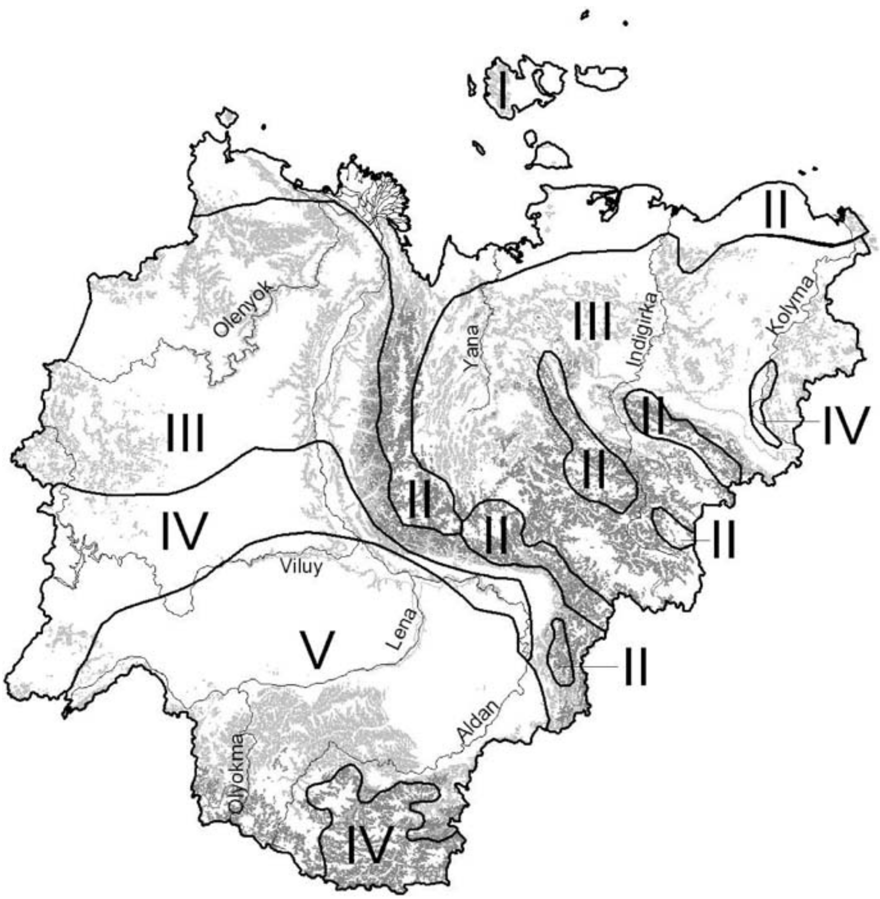

Fig. 1.7 Thickness of seasonally thawed soil zones in Yakutia

under the northern taiga and 30.5% is tundra. Thus, soils of the tundra and taiga landscapes form the basis of the soil cover structure (SCS) of Yakutia. And within those categories highland landscapes in the tundra and taiga prevail, accounting for 18.3 and 22.4%, respectively (Elovskaya et al. 1979).

1.5.1 Tundra Soils

Frozen tundra gleyey soils are formed in watershed landscapes of spotty and small hillock tundra common in the south of the arctic tundra and in the north of the sub-arctic tundra. These automorphous soils are characteristic for relatively well-drained sites with strongly pronounced, scattered hillock microrelief induced by frost fracturing. The fractured surface consists of flat, fairly well recognizable polygons as