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IIASA International Institute for Applied Systems Analysis • A-2361 Laxenburg • Austria
Telephone: +43 2236 807 • Telefax: +43 2236 71313 • E-Mail: info@iiasa.ac.at

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Foreword

This is the time Siberia's forest sector has recently gained considerable international interest. IIASA, the Russian Academy of Sciences, and the Russian Federal Forest Service, in agreement with the Russian Ministry of the Environment and Natural Resources, signed agreements in 1992 and 1994 to carry out a large-scale study on the Siberian forest sector. The overall objective of the study is to focus on policy options that would encourage sustainable development of the sector. The goals are to assess Siberia's forest resources, forest industries, and infrastructure; to examine the forests' economic, social, and biospeheric functions; with these functions in mind, to identify possible pathways for their sustainable development; and to translate these pathways into policy options for Russian and international agencies.

The first phase of the study concentrated on the generation of extensive and consistent databases for the total forest sector of Siberia and Russia. The study has moved into its second phase, which encompasses assessment studies of the greenhouse gas balances, forest resources and forest utilization, biodiversity and landscapes, non-wood products and functions, environmental status, transportation infrastructure, forest industry and markets, and socio-economic problems.

The work underlying this report has been carried out by a team under the leadership of Prof. V. Roshkov from the Dokuchaev Soil Institute in Moscow. The report presents the results from this work with bearing on the assesment studies of biodiversity and landscapes mentioned above and is produced by Prof. V. Rashkov and Dr. V. Wagner of the Dokuchaev Soil Institue in Moscow, Dr. D. Efremov Far East Forestry Research Institute, Khabarovsk, Dr. V. Sokolov Sukachev Institute of Forestry, Krasnoyarsk, Professor V. Sedych, Dept. of Forest Dynamics, Novosibirsk Forestry Branch, Novosibirsk and Professors S. Nilsson and A. Shvidenko from the study's core team at IIASA.

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1. Background

The study "Siberian Landscape Classification" (SLC) is part of IIASA's Siberian Forest Study.

The main tasks of this substudy are:

1. To develop a uniform classification of Siberian landscapes as a basis for evaluation of biodiversity and bioproductivity and for forecasting the dynamics and development of the landscapes under conditions of natural and antropogenic disturbances.
2. To generate a database of the Siberian landscapes which could be used for quantitative parametrization of the landscapes.
3. To generate a digitised map of the Siberian landscapes in the scale of 1:1,000,000.

To accomplish the tasks, the following steps were performed:

1. Two workshops with the involved experts were organised in order to design the project.
2. Data on landscape characteristics were collected and generalised, landscape taxonomy and the structure of the database were developed.
3. Based on the collected data a landscape matrix was generated. The matrix was developed in order to create a hierarchical description of the landscapes.
4. A digitalized landscape map was produced.

The following scientists carried out the basic calculations: N. Belousova, B. Gradusov, V. Kiseleva, D. Ruchovich, I. Shubina from the Dokuchaev Soil Institute and M. Karachevsky, and O. Liss from the Moscow State University. Academicians A. Isaev and Y. Voronin acted as consultants to the study.

2. Analytical Review

2.1. The Russian Landscape Concept

The idea of a landscape approach has always dominated (directly or indirectly) in Russian schools of natural sciences. The first attempts to regionalise the territory of Russia were made in the middle of 19th century. During the last century, the term "landscape" meant "a picture of a section of a natural inland scenery" and served mostly as an emotional perception of nature. The landscape concept of the Russian natural scientists at that time was a kind of Eurasian vision of the World, combining the analytical thinking of Europeans and the imaginary views of Asians.

Trautfetter (1891) identified four areas in his concept: 1) Northern Russia, or the area of tundra; 2) Western Russia, or the area of Norwegian spruce; 3) Eastern Russia, or the area of Siberian conifers; 4) Southern Russia, or the hard-deciduous forests (cited in Natural-historical regionalisation., 1947).

Menzbir (1882) distinguished basic landscapes of the country by vegetation types and named them as strips of tundra, taiga, isolated forests, steppes, coasts, islands, and deserts. Keppen (1885) used geographic notions (Crimea, Caucasus) as well as soil-landscape identifications such as tundra and chernozems. Tanfil'yev (1897) suggested a division of Russia into physical-geographical areas, where the recognition of the regional level was based on vegetative peculiarities and geological conditions: sandy and clayey soils, stony tundra, extraglacial pre-steppe, steppe lakes, solonets, and solonetsic chernozems.

Dokuchaev is considered as the founder of the soil-botanical (ecological) regionalisation and was the first to suggest the principle of natural zonality in his book "The doctrine of natural zones" (1899). The basic principle for his regionalization is based on the interrelations between climate, plants, animals, and soils. Later on, he formulated the principle of vertical zonality. His ideas were later further developed by his scholars (Vysotskiy, Savitskiy, Glinka, Korzinskiy, Neustruev, Polynov, Prasolov, Sukachev, Gerasimov and others).

Work by Komarov (1921) and Berg (1922) stressed the mutual dependence between the structure and specific features of organisms on one hand, and landscape conditions on the other hand.

Semenov-Tyan-Shanskiy (1936) gave the following characteristics to a landscape: "...certain, harmonic, and regular pictures typical for a specific location". His opinion was that physical geography is crucial for the identification of landscapes.

The definitions used for landscapes are different for different authors. This is clearly demonstrated in Table 2.1, containing zone names used by different authors.

Table 2.1. Natural zones of the Former Soviet Union

Zones	Authors										
	1	2	3	4	5	6	7	8	9	10	11
1. Glacial areas	-	-	+	-	-	-	+	-	+	-	-
2. Arctic deserts	-	-	-	+	+	+	+	+	+	+	+
3. Tundra	+	+	+	+	+	+	+	+	+	+	+
4. Forest-tundra - open forest	-	+	+	+	+	+	+	+	+	+	-
5. Pre-oceanic deciduous open forests and meadows	-	-	-	-	+	+	-	+	+	-	-
6. Taiga forest	+	+	+	+	+	+	+	+	+	+	+
7. Mixed broad-leaved forests	-	+	-	-	+	+	+	+	+		
8. Mixed forests of the Russian plain	-	-	+	-	-	+	+	-	-	-	-
9. Mixed forests of the Far East	-	-	+	-	-	+	+	-	-	-	-
10. Deciduous forests	-	-	-	-	-	-	-	+	-	+	-
11. Forest-steppe	+	+	+	+	+	+	+	+	+	+	+
12. Steppe	+	+	+	+	+	+	+	+	+	+	+
13. Dry steppe	-	-	-	-	-	-	-	-	+	+	+
14. Semideserts	+	+	+	+	+	+	+	+	+	+	+
15. Deserts	+	+	+	+	+	+	+	+	+	+	+
16. Piedmont desert-steppe	-	-	-	-	-	-	-	-	+	+	+
17. Subtropical deserts and semideserts	-	-	+	-	+	+	+	-	-	+	+
18. Subtropics	+	+	+	+	+	+	+	+	+	+	+
19. Mediterranean (dry subtropics)			+	+		+			+	+	+
20. Subtropical evergreen forests	-	-	+	-	+	-	+	-	+	+	+

Authors: 1. Berg, 1947; 2. Makeev, 1956; 3. Milkov, 1977; 4. Alpatyev et al., 1965; 5. Kolesnik, 1970; 6. Prokaev, 1983; 7. Atlas, 1984; 8. Kurnaev, 1973; 9. Isachenko, 1988; 10. Nature-agricultural..., 1983; 11. Dobrovolskiy and Urusevskaya, 1984.

"+" designates used zone names

"-" designates not used zone names

It is likely that the divergence in usage of terms is provisional. Nevertheless, there is a widely used conception of zonal division of the former Soviet Union and Russia. However, the zonation is not always corresponding to a latitudinal division.

Some authors divide the zone of broad-leaved forests into forests, the Russian plain, and the Far East. There are climatic variations within a zone, and the landscapes within a zone vary too (Solntsev, 1948, Polynov, 1956a, Karpachevsky, 1983). Therefore, the zones may be sectional and provincial, reflecting specific features of natural conditions over a area of former Soviet Union or Russia. Soil-climatic belts are recognised in mountainous areas. However, zonal-vegetative names are more frequent in the nomenclature of landscape units. It is rather difficult to generalise and adjust the concepts of subzone borders as the scientists of different disciplines use their own subdivisions. However, there is a certain consensus and intuitive understanding on how an area is arranged, allowing foresters, geobotanists, soil scientists, geophysists, landscape scientists, and climatologists to speak the same language (Vasiliev 1947; Goebotanical regionalization 1947, Geomorphological... 1947; Troitsky 1948; Lavrienko and Sochava 1954; Polynov 1956b, Gvozdetsky 1967, 1973; Prokaev 1967; Voskresensky 1980, Aleksandrova 1989).

At present, there is an increasing interest in landscape research in different fields of science in Russia. Landscape approaches are applied to studies of negative technogenec impacts (Kupakova and Milanova, 1972, Landscape-geochemical regionalization...1983, Krenck 1989, Gadzhiev 1990, Volkova 1990, Ecology and recovery...1992), to landscape architecture (Vergunov, 1991), ecology (Shasko 1967, Dobrovolsby 1981, Ecological-geographical regionalization of Siberia, 1990, Landscape basis...1990, Ecological foundations..., 1994), and land-use planning (Soil-geographical...1962, Chupakhin, 1987; Chupakhin, Andriishin, 1989). The landscape concept is especially important for landscape agriculture (Agriculture...1989; Kiryushin, 1993; Volkova, 1990; Landscape farming, 1993; Ecological foundations..., 1994).

The landscape approach also seems to be the basis for modern Russian forestry concepts (Kurnaev, 1973; Kireev, 1979; Puzachenko and Skulkin, 1981), for forest inventory (Kolesnikov, 1973, 1977, Landscape taxation, 1977; Proceedings...1977, Smagin 1977, Kalashnikov, 1981; Kireev, 1966), and for forest management (Kalashnikov, 1987; Kireev, 1966; Sheinganz 1985, Shehetnikov, 1989, Sedykh, 1991; Kireev and Sergeeva, 1992, 1995).

The Russian historian Gumilev made an attempt to establish a dependence between the appearance, development, and decline of ethnoses, on one hand, and peculiarities of landscapes, on the other. His numerous studies, published only recently, consider geography of ethnos (1990a), ethnogenesis and biosphere of the World (1990b), ethnosphere, or the history of mankind and its relation to the evolution of nature (1993), and development patterns of civilisation in Eurasia (1993b). According to Gumilev, people create their culture under the conditions of diverse landscapes and bring this diversity into vast uniform landscapes. He speculates that "a monotonous landscape stabilises ethnoses, while heterogeneous landscapes stimulate changes, leading to the formation of new ethnic groups" (Gumilev, 1990a, pp.192). Therefore, "...we have to start study the history of nations for a description of nature and climate." (Gumilev, 1992, pp. 20). Ethnic landscapes of Eurasia have been determined as well as the role of anthropogenic impacts forming landscapes (Gumilev, 1993).

In this respect, it is worth to mention a notion by another notorious modern Russian writer, namely V. Soloukhin who stresses that a landscape with all its complexity, is not just a part of the face of the Earth or a country, but a face reflecting a community.

2.2. Some Definitions and Concepts

The complexity and variability of ideas about landscapes stemming from various goals, means of description, and ways of realisation need a strong aggregation in order to be operational. Relief and associated landforms conditioned by hypsometry and rocks are the basis for landscape determination in geomorphology and physical geography. Biogeographers determine landscape by biogeocenoses, i. e. by the existing vegetation and habitating animals. Soil scientists consider soils to be "the mirror of landscapes". Landscape scientists identify the landscapes by relief geology, and by the appearance of living organisms. Used landscape definitions are more or less unique in the different and most authoritative studies.

Savitsky (1927) defines a landscape as "a part of the land surface, which is substantially distinct from other sites fringed by natural borders and representing the entire and an interrelated regular assembly of objects and phenomena, which is recognised over significant space and with unbroken links of all relations forming a landscape shell" (cited by Gumilev, 1990, p.186).

Sukachev (cited by Zonn, 1987, pp. 127-128) considered the definition made by Solntsev (1948) to be relevant: "The geographic landscape is a genetically homogenous area with a regular repetition of interrelated combinations like the geological structure, landforms, surface and ground water, microclimate, soil, phyto- and zoocenoses".

Berg wrote in 1931, that "a geographical landscape is a total or a group of objects and phenomena, with certain peculiarities concerning relief, climate, water, soil and vegetative cover, and animal habitat, as well as of human activities, repeated in a harmonised way over a known land area" (cited by Sukachev and Dylis, 1964).

Berg (1930) considered Dokuchaev to be the founder of the landscape doctrine (cited by Polynov, 1946), who first phrased the soil to be "the mirror of landscapes". The soil naturally combines relict and contemporary features of a landscape. The soil appears to be the aggregated sum of the interaction of all natural conditions and factors. "The soil appears to be... a complete reflection of other elements of a landscape; it essentially differs from animals, plants, and parent rocks as it does not have its own unique origin. It does not emerge from outside in order to fit into a given landscape; it represents the creation of a landscape from the very first moment of the formation and therefore reflects the landscape properties to a much greater extent than any other element". As a matter of fact, the doctrine of landscapes distinguish between old (inherited) landscape elements and new ones (progressive), besides those equilibrated by the environment. Soils appear to be bearers of both relict and progressive features of landscapes (Polynov, 1946). Differences found in soil and vegetative cover of a landscape are not due to global climatic factors but to regional and provincial peculiarities.

A landscape is considered as a combination of natural components such as geological history, reliefs, soils, plants, etc. and as a relatively unified physical-geographical complex (Gvozdetskiy, I979, pp.131). Therefore, the zonal variations in a set of soils and vegetative associations are absent in landscapes, but intrazonal formations are present (Solntsev, 1948, Milanova and Ryachikov, 1986, Landscape farming, 1993).

It is important to include biogeochemical cycling and component structures (Ryabchikov and Tarasov, 1986) in the concept of landscapes, besides the regularity of all the components and history of the landscape.

Armand (1975) made a comparative analysis of presented terms of ecosystems, geosystems, natural area complexes (NAC), and landscapes, and found two dominating characteristics for landscapes:

(1) landscape is a district or a part of a district of a certain taxonomic rank, i. e. the synonym of NAC (Milkov, 1977, Prokaev, 1983, Solntsev, 1948, and Armand, 1975);

(2) landscape is a certain class of numbers of site types (Polynov, 1956b).

However, by only demonstrating a correlation between geosystems and landscapes, the distinction between the two entities are nearly lost. Nevertheless, the first definition is more specific.

By location of the relief, the following groups of landscapes were determined by Polynov (1956b): (1) eluvial, (2) superaqual, and (3) subaqual landscapes. Transeluvial, transsuperaqual, and transitional groups were added later, since climatic variations are always present within a zone, and landscapes are not identical but similar within a zone (Figure 2.1).

This division became a basis for modern land typology in agrolandscaping for description of watersheds, close-watersheds, near-network, and hydrographic lands (Kiryushin, 1993). In this case, an agrolandscape is regarded as "part of a geographical cell separated during its evolution and used in agriculture" (Landscape agriculture, 1993). To classify agrolandscapes, formalised methods were suggested, based on the ratio between the precipitation and (or) so-called productive moisture (a difference between the total sum of precipitation and the runoff), and active temperatures (Ryabchikov and Tarasov, 1986). As a result, more than 700 natural complexes were described, each of them having a specific set of agricultural characteristics.

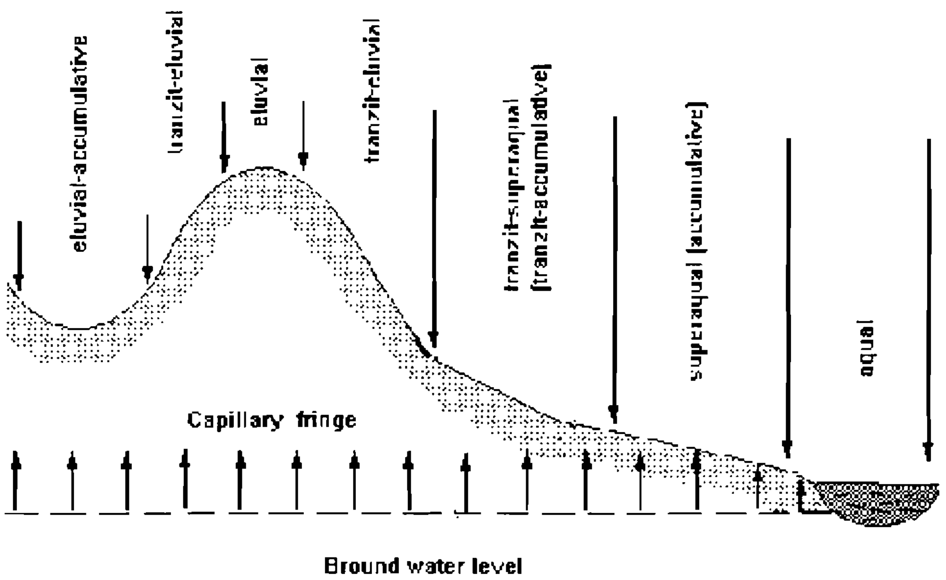


Figure 2.1. Associated geochemical landscapes.

In addition, there are technogenic, settlement, recreational, and other landscapes identified (Chupakhin, 1987; Chupakhin and Andriishin, 1989; Volkova 1990; Vergunov 1991; Ecology and recovery..., 1992; Landscape farming, 1993; Ecological foundations..., 1994).

An important question is how to determine the area of a landscape. Direct measurements are absent. It is possible to speak about "the landscape of a forest meadow " on one hand (Armand, 1975), and about the areas of hundreds and thousands of square kilometres (Ryabchikov and Tarasov, 1986) on the other hand.

In order to minimise terminological disagreement and uncertainties in this study, the following definition of landscape was adopted for the analysis of a taxonomic structure: "a natural complex which is homogenous in zonal and azonal aspects, with uniform climate, general relief type, homogenous foundation, and homogenous morphological structure" (Voronina and Isachenko, 1983, pp.70).

According to Russian classification, landscapes with a similar structure of their components and internal interaction by the components, can be aggregated into "landscape types."

Landscapes can also be subdivided into "terrains" (mestnost). A "terrain" is defined as an ecological system (a natural area complex, NAC), which is part of a landscape and is characterised by relief, quaternary deposition of the same genesis, soils of the same origin, similar hydrographical net, and similar phyto- and zoogenosis. "Terrains," which are similar in structure can be aggregated into "terrain types."

A "terrain" can be subdivided into "stows" (urochine), which are specific genetic units of the mesorelief and separate elements of a hydrographical net (lake, river, mire), which are characterised by a definite biogeocenotical (facieal) structure and by linkages between biogeocenosis (facies). "Stows" similar in structure can be aggregated into "stow types." Thus, "facie" or biogenocenosis (Sukachev and Dylis, 1964) is the smallest unit in the classification. In this report we have only taken the top level of the classification - the "landscape" - into account.

3. Database for a Landscape Classification

The database for the landscape classification was generated with the objective to integrate different landscape concepts in a unified system.

There are two dimensions of this task. First, there is a need to create a general concept and principal structure in order to unify the architecture of existing classifications. Second, there is a need to place the existing classifications in this structure.

The work carried out is based on the theory of enumerative classification formulated by Voronin (1985). His concepts were tested in a logical calculation system called MERON used for the generation of an International Data Reference Base for Soil Classification. This system allows to determine the degree of similarity of taxonomic units of the soil classification systems of FAO, Russia, and the USA (Classification, 1989). Enumerative classification of landscapes is a database, taking into account ideas of different investigators. According to Voronin (1985) this system can:

- formally organise the extent and content of a landscape by integrating specified properties;
- generate a basis for design and control of concepts for a set of landscapes;
- serve as a mean for and efficient coding of empirical data of a set of landscapes;
- provide input of a whole system of names to a set of landscapes and a possibility for changes of names; and
- provide a possibility for optimisation of empirical investigations.

The enumerative classification of landscapes catches many classification principles adopted by different authors. Attributes of landscapes are designated by their names and values. They can by nominal, binary, ordinal or arithmetical (Voronin, 1971). The latter are continuos or discrete, i.e. they are shown by the number of accepted value intervals. The concrete values are names as in the form of gradations. Thus, plane, hill, piedmont, plateau are found to be gradations of nominal attributes, named as relief; oceanic, middle continental, continental, very continental, which are gradations of ordinal attributes, inherent to landscape sectors, etc. Taking into account a number of attributes (j=1,2...., m) and their values (Kj) there is a possibility to determine a theoretical (upper level) of the number of landscapes, to be determined. The total amount is determined as a cluster of subsets suggested by experts. The theoretical background for the set of landscapes equal to the De Cartes' product of a number of gradations, describing features of landscapes (Kj):

$$\overset{m}{\underset{j=1}{N}} = \overset{m}{\underset{j}{Kj}} = \prod \{K1 * K2 * \ldots * Kj * \ldots * Km\} \quad (1)$$

The enumerative classification resulting from selected features may be displayed as a decision tree (Fig. 3.1):

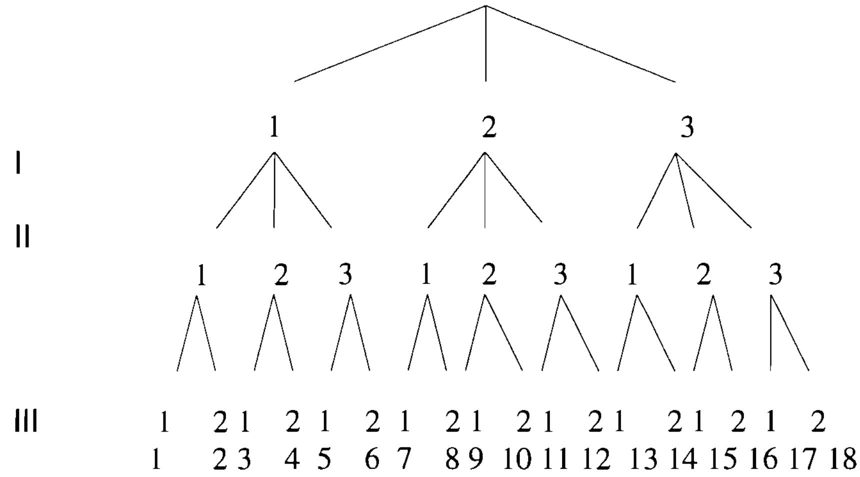


Figure 3.1. The concept of enumerative classification
(K3)=3, 3, 2; N=3*3*2=18

The figure shows that the three attributes have: I-3, II-3, and III-2 graduations of their values, and hence the combination of the graduation may reflect 18 different objects.

The real diversity of objects is less than the theoretical diversity, due to the fact that some combinations of features do not exist in nature, while others indicate a not yet described landscapes. Apparently, the selection of the parameter list is a very important phase of the construction of an enumerative classification.

In most cases, existing classification systems use the following parameters for determination of a landscape: the geographical location (radiation and thermal regimes, moisture conditions); relief (morphology, genesis, age, and dissection); lithology (geological bed rocks and deposits, drainage); hydrology (types of lakes and rivers and their properties); vegetation (types of phytocoenoses, species composition, area covered by forest, productivity); and soil (soil pattern). The degree of subdivision with respect to slopes and vegetation determine the division of landscapes into smaller units.

At the classification of forest landscapes, some researchers use physical geography (e.g. Kireev, 1966, 1976, 1979; Kalashnikov, 1981, 1987). The generalised and small-scale landscape regionalisation aiming at forest mapping (Kireev and Sergeeva, 1992) corresponds completely with the physical-geographical classification.

An optional way to recognise subzones of landscapes in Siberia is by the geographical zonality (Kolesnikov, 1956; Gvozdetsky, 1973; Kurnaev, 1973; Sedykh, 1991). In this approach the structure of the vegetative cover is a function of local thermal and hydrological regimes. The regimes are effected mainly by the geological structure of an area and by the relief, under similar climatic conditions. Geomorphology and lithology, as well as parent materials, vegetation, and corresponding soils, also serve as basis for the landscape recognition (Sedykh, in press).

Regional classifications are quite numerous. Some of them regard local peculiarities in details (Ilina et al., 1985; Permafrost landscape map of Yakut ASSR, 1989; Kireev and Sergeeva, 1995).

In addition, approaches like the integral landscape construction have been established (e.g. Gvozdetsky and Mikhailov, 1987; Gudilin, 1987; Isachenko, 1988).

This study does not comprise a critical analysis of the attributive systems used by the numerous authors for landscape classifications. The approaches used have a quite similar subdivision principle at a high taxonomic level. The distinctions of the taxonomic levels do not effect the classification procedure. Differences arise, when graduations of attributes are specified to be: macro-, meso-, and nanorelief; and type, subtype, and variety of soil, etc.

The main source for generation of the database for the enumerative classification in this study was the landscape classification used by Gudilin (forthcoming) for the creation of a landscape map in the scale of 1:2.5 million. This is the current most complete classification in Russia. Decoding of air and space photos of the whole area of the former USSR was widely used for this kind of map compilation. The main reason for choosing this approach is the close relationship between morphological and spatial peculiarities of the landscapes, and the possibility to establish their genesis. The map was based on geological-geomorphological, bioclimatic, and soil peculiarities of the areas. Geological-geomorphological properties of landscapes play a leading role in the delineation of borders of landscape classes, genera, and variants of genera. It is much more difficult to recognise borders linked to bioclimatic properties of landscapes. In this case, the main difficulty is to decode the contour of landscape types and subtypes, and to determine the structural types of the image drawings. At photos, borders between zones and subzones are often linked by stripes of a gradual transition, therefore the separation is possible only with the help of supplementary maps (soil and geobotanical maps, etc.).

The landscape was considered as the main objective of the identification, e. g. "natural area complex, homogeneous in genesis, undividable by zonal and azonal characteristics, having a certain geological structure linked to a uniform relief, a similar combination of hydrothermal conditions, soils, biocoenoses, and representative only for the specific area studied with an internal structure of small natural complexes ..." (Explanatory note..., 1987).

The following taxonomic levels of classification are adopted for terrestrial landscapes (Fig. 3.2):

DIVISION (there are two), the separation is based on the regularities of the tectonic structure of the Earth displayed in the geomorphology;

GROUP (total 19) is recognised by the macroclimatic, soil, and vegetation features. The division is based on a latitudinal-elevation zoning and on the degree of climate continentality;

CLASS (4 total) identified by the geomorphology of the landscapes, based on the occurrence of mountains and plains, and by inter-platformal mountains, intermountain, and piedmont plains;

TYPE of landscapes (15 for plains and 19 for mountains) is determined by all enumerated properties: hydrothermal, soil and vegetation features or class, and by group of geomorphological characteristics;

SUBTYPE of landscapes are subordinated to a type and depend on the prevailing soil subtype, and the group of vegetation as formation. The altitude is also taken into consideration in mountains (low-, middle-, and high mountains). In general there are about five gradations of subtype properties.

GENERA (50 total) of landscapes are determined by geologo-geomorphological features; morphosculpture (species of deposits) and morphostructure (genesis, texture, and age).

VARIANT is determined by the location of a landscape in the geomorphological regions and has specific regional features. The following variants of landscapes are recognised in Siberia: Middle Siberian, Western Siberian, Taimyr-Severnaya, Zemlya, Altay-Sayans, Prebaikalian-Transbaikalian, Northeastern, Daur-Far Eastern, and Sakhalin-Kamchatka landscapes. The regional character of this taxonomic level is apparent and disturbs the hierarchical principle of the classification. Therefore, variants are not applied in the formal estimates, although they may be displayed on the map.

SPECIES is a set of individual landscapes similar in genesis and structure. The similarity of small sites, dominating within a landscape, closeness of mesolandforms, the unity of vegetative cover at the level of associations and formations and soils linked to them, features of contemporary physical-geographical and geological processes, and the degree of land cultivation were used for the identification of species of landscapes. A revised classification of the main types (groups) of Pre-Quaternary rock formations also served as basis for the recognition of species of landscapes. Classifications adopted in "The engineering-geological map of the USSR in the scale of 1:2.5 million" and in "The map of Quaternary deposits of the USSR in the scale 1:2.5 million" were used to classify genetic types of loose Quaternary deposits.

Nevertheless, some shortcomings common for all attempts of regionalization still persist in the classification. First of all, it is a descriptive character of the features of the landscape, where properties do not have clearly designated quantitative values and ranges. Moreover, similar descriptive characteristics are relative and may have different meanings in different climatic and lithological zones, i. e. in strong and medium dissected reliefs, gentle and steep slopes. The recognition of some taxonomic units (e.g., vegetative associations and soil) is rather general. Vegetation is described at the level of subtypes, that implies a relatively rough description for each contour. The soils of the contours are just enumerated but do not have identified fractions of the total area and of the soil pattern. The amount of possible combinations of features (hundreds of thousands) is significantly greater than the number of recognised contours (thousands in reality). Therefore, the legend of the map has many empty entries. The amount of possible taxons of enumerative landscapes at the level of genera gives:

Group Type Genera

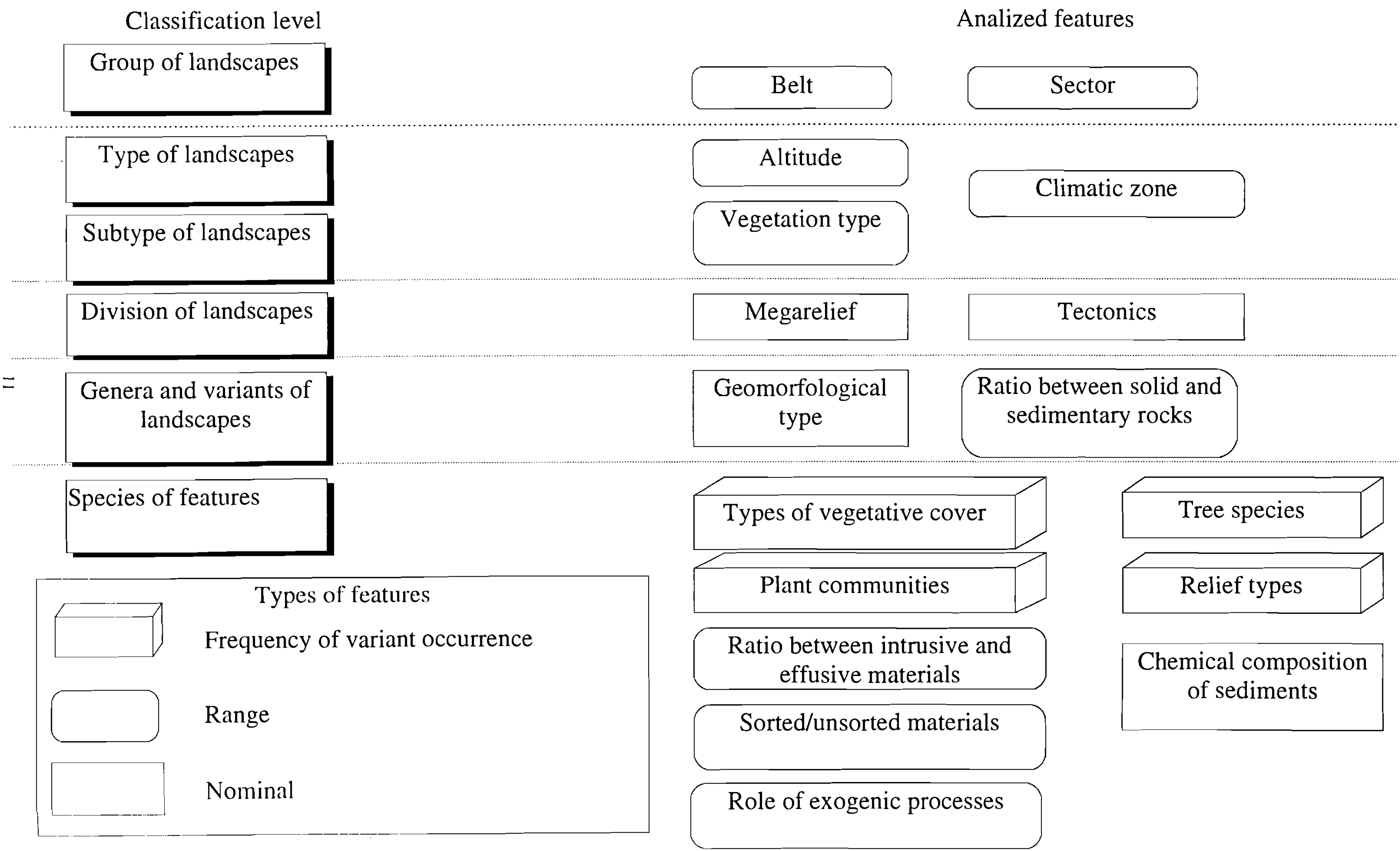
N = 2 * 19 * 4 * 19 * 5 * 50 = 722000.

Division Class Subtype

At the level of species, the amount of taxons increase by two times. In reality, about four thousand contours are identified in the map. It means, that the database is too excessive. However, the database allows to "enclose" the features described by many authors, and there is a way to optimise the descriptions of natural area complexes. The earlier described mathematical method seems to be efficient for this optimisation.

The actual parameter gradations, adopted for the numeration of landscapes, are grouped and compiled in Appendix 1.

Fig. 3.2. The Gudilin classification of landscapes for statistical analysis



4. Formal Design and Methods for Landscape Classification

4.1. General Definitions

A comprehensive classification system is an information system containing maximum information about objects in a given space of attributes. The attribute is a double spaced predicate comprising Name and Values. Object is a structure, fixed in space of attributes.

The classification has different objectives (Voronin, 1970, 1985):

1. to divide objects into classes
2. to systemize identific or adopted classes
3. to attribute objects to one of the classes.

Let us make a formal definition of the landscape classification.

A is a set of objects (A) divided into classes as follows:

$A = A_j$, where j =1,2,...,k and k is the number of classes

$A_j \neq \varnothing$ - e.g. classes with a concrete content (not empty)

$A_j \cap A_l = \varnothing$, where i, j = 1,2,...,k and $j \neq l$, e.g. there is no transition

$\bigcup A_j = A$ - union of classes equal to an initial set.

Distinguished classes are called equivalent classes.

Equivalent relations possess the following properties:

- reflexivity (xRx)
- symmetry (xRy ==> yRx)
- transitivity (xRy & yRx ==> xRz).

Hence, in this case the landscape classification is the elaboration of a certain system of determined classes (equivalence of classes).

4.2. Attribute Scales

The landscapes are represented by a great number of different property characteristics. Therefore, there is a necessity to systematise the attribute scales with respect to the measurements. These scales mean the total of the values inherent to features, the transformation and the processing of the same.

To distinguish the scales, the principle of possible transformations of values is used. It determines the possible arithmetic procedures and methods for the processing. Basic properties are not changed after transformation. It is important that the results of arithmetical procedures and the relationships between the characteristics also remain unchanged (Voronin; 1971 Vysokos and Roskov, 1981, 1989).

To describe the landscapes, the following scales are used: (1) nominal, (2) ordinal, (3) binary and (4) arithmetic (in some cases). These are the attributive scales which serve as characterisation of the landscape. The first three scales have proved to be sufficient to resolve geological and geographical problems. (Voronin, 1971).

Attributive scales (nominal or classificational) includes names, indices, and codes of objects or abstract numbers. For these values, only coincidence or lack of coincidence between two compared objects can be settled. Using the total information for an object, there is a possibility to determine the frequency of every feature. No average values are needed in this case, only modal value is determined. The total information for an object can be compared by using the frequency of synonymous features, i.e. qualitative indices help to elaborate the quantitative ones.

Binary values (dichotomous, alternative) are also quite common and comprise two possible values: 0 or 1 (present-absent ratio), for which the same procedures are applicable. A binary scale was used to transform the description of the landscape divisions.

The ordinal or rank scale is used to show the order of values apart from their coincidence or lack of coincidence. Such approach assumes that the "more or less" ratio is equal to the "equal-unequal" one, and applies to the determination of the median and centiles of the frequency distributions. Conjugation of synonymous features is estimated based on the correlation between ranks or classes. In this case averages and other statistics of parametric patterns can not be used but non-parametric indices are found to be suitable. Features, measured in an ordinal scale, are considered as qualitative ones, capable to be ranked in terms of their similarity or their genetic position. Rank scales are the most used in landscape descriptions. For arithmetic values, any procedures and simple processing can be used.

The scale is considered as strong if the procedures have been determined and constitute a part of those suitable for other scales. A transition from a strong to a weak scale is named scale coarsening.

4.3. Formalisation of Landscape Description

Landscapes have proved to be multiparametric, being described by a whole complex of features; it means that simultaneous observations of the total information on an object permits to make a multiple selection X :

$$\mathrm{X} = x_{ij} = \begin{bmatrix} x_{11} x_{12} \cdots x_{1j} \cdots x_{1m} \\ x_{21} x_{22} \cdots x_{2j} \cdots x_{2m} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ x_{i1} x_{i2} \cdots x_{ij} \cdots x_{im} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ x_{n1} x_{n2} \cdots x_{nj} \cdots x_{nm} \end{bmatrix}$$

The observation matrix has *n* lines corresponding to the number of objects under description and m columns according to the number of features.

Due to the variability of the features, the landscapes occupy some places or "spheres" within the space under survey. There are 3 types of relationships between the spheres: inclusion of one sphere into the other, intersection (partial inclusion), and non-crossing. Quantitative indices are given for these relationships.

4.4. Formalisation of Relationships Between Objects and Classes

The concepts of difference and similarity are believed to be basic in any classification. In the general case, they are determined by quantitative indices, based on the soil features. For nominal and binary scales, the following function is frequently used:

$$d_{il} = = \frac{1}{m}\sum_{j}^{m} p_j$$

where $p_j = 0$, if $x_{ij} = x_{lj}$ and $p_j = 1$, if $x_{ij} \neq x_{lj}$.

For the ordinal scale, the so-called "Canbèrra metric" is applied:

$$d_{il} = \frac{1}{m}\sum_{j}^{m} \frac{|x_{ih} - x_{lj}|}{k_j}$$

where j is the number of a module; k_j is a number of the values of gradations for the j-th feature.

In analytical geometry, a distance between two points, is regarded, in a given case, as the difference between two objects in m arithmetic features, and is expressed by Euclid's metric:

$$d_{12}^2 = \sum_{j=1}^{m} (x_{1j} - x_{2j})^2$$

Thus, for any pair of objects, an average distance (or difference) of all m features within one scale is always formulated as follows:

$$d_{il} = \frac{1}{m}\left[\sum_{j=1}^{m} \frac{(x_{ij} - x_{lj})^2}{w_j}\right]^{\frac{1}{2}}$$

As a normalised number, ***Wj*** may serve as:
1) dispersion of j-feature;
2) amplitude of its values [X(max, j) - X(min, j)],
3) maximum value, X(max, j),
4) sum of values to be compared, [X(i, j) + X(l, j)].
A similar approach proved to be co-equivalent for distances. When ***Wj*** has 2-4 numbers, the similarity is expressed in the following way:

$$s = 1 - d$$

However, so-called potential functions are frequently applied. For example, describing changes in electric potential dependence on its distance from the charge source. The following functions are widely used:

$$s = \exp(-d)^2 \qquad \& \qquad s = \left[(1+d)^2\right]^{-1}$$

Similarity of classes among the objects is also determined by using the same indices. In particular, it may be an average similarity of objects within one class with those of other classes (method of average similarity):

$$d_{fk}=\frac{1}{n_f * n_k}\sum_{i=1}^{n_f}\sum_{l=1}^{n_k} d_{il}$$

where d(f,k) is the distance between the f-th and k-th classes and the number of objects n(f) and n(k); d(i,l) is the distance between i-objects of the first class and j-objects of the second class.

As an index of similarity/difference for classes a distance between centres of classes may be used (centroidal), as well as the distance between the nearest ("nearest neighbour") or most distant ("distant neighbour") objects of the classes.

Based on their similarity, the objects can be grouped into classes with the help of the procedures, listed above. The result of such groupings is an ordinate or hierarchical structure designed to reflect the taxonomy of the classification (Figure 4.1).

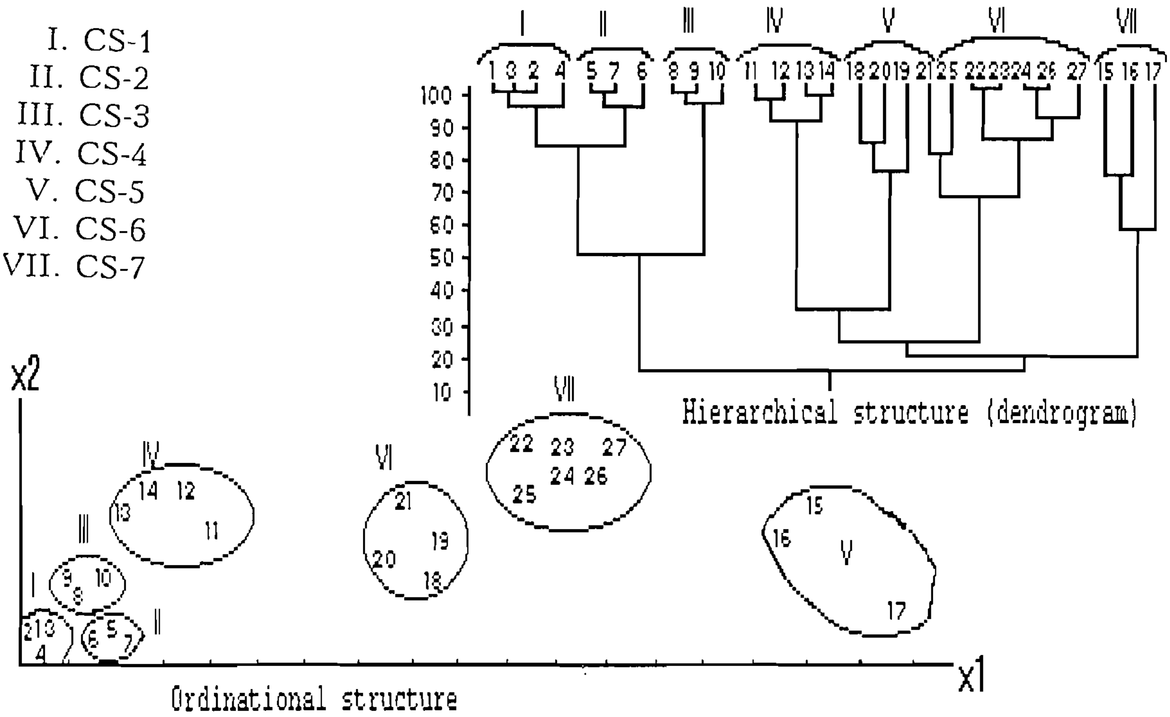


Fig. 4.1. Ordinate classification and dendrogram

Dendrogram appears to be a very suitable way to demonstrate the classification of multiple objects. They show the relationships between classes and permit to give a clear picture of the relationships between objects and classes in a structural form. The latter may be a system based on the concept of similarity.

Within a class, it is possible to find a holotype, i.e. an object which is the most similar to other objects of the same class. The typical nature (typification) of objects is expressed as follows:

$$t_i = M_i[1 - 1/n\sum_{j}^{n}(\dddot{M}_i - M_{ij})^2], \text{where} \dddot{M}_i = 1/n\sum_{j}^{n} M_{ij}$$

$$t_k = \max t_i, i = 1 \ldots n$$

Holotype is an object with the maximum t_i being the most specific. On average, it appears also to be the most similar to other objects of the same class. (Voronin and Cheremisina, 1971).

4.5. Informativity of Features

In the classification procedure, the information from the features is most important for the division and description of landscapes. The more the feature is able to show the difference between landscapes, the more informative it is.

There are numerous approaches to determine quantitative indices of the information of the object features and their classes, especially for arithmetic values (Roskov, 1989, 1993). However in our case, it is important to emphasise the qualitative scales.

As any scale, the most efficient information features are those connected with similarities or differences (Roskov, 1993). They are determined with the help of a transposed matrix for the object description (see paragraph 4.3). Very similar features are excluded sequentially until the most important feature remains to give reliable information. Formal features or expert assessments are used as criteria. Dendrograms compared by initial or reduced set of features (Sokal and Rohlf, 1962) appear to be most efficient for this purpose.

A correlation coefficient for several features may serve as an index on the extent of information. It is reasonable to use only one of two correlated features, because a second one can not provide any additional information. These two approaches may be combined in order to choose the most informative properties for the elaboration of a system of informative characters. Moreover, from a set of features chosen by the first criterion, the features which are weakly connected to each other are left out.

The method of basic components proved to be the most convenient; it permits to establish significant differences of features and to choose the most informative ones.

These methods can be used together in a dendrograph in order to divide objects into classes. However for these purposes the "method of occasional search combined with adaptation" is more efficient (Lbov, 1981; Roshkov, 1989). The main characteristics of this method is an occasional search of the total feature, the search of diagnostics (recognition) errors, and the object attribution to corresponding classes. In addition, the method comprises the determination of the influence of the most important feature among those with a non-zero influence. This procedure is carried out faster than that connected with the examination of all possible combinations of features. The diagnostic methods are described below.

4.6. Diagnostic Classification

Diagnostics means the determination of any object and its attribution to a certain class. Various methods are applicable for this kind of diagnostics. The simplest but less reliable ones are the methods based on difference or similarity indices.

To make diagnostics of objects, referred to certain classes, there is also the possibility to use the "method of the most distant neighbour". It includes the determination of the difference between the distant element and the centre of the class. The method of average similarity of all of the objects of the class (average connection) and centroidal method determining the closeness to the class centre can also be applied.

The discriminant analysis has proven to be the most efficient diagnostic approach. The main approach by this latter analysis is to find a plane dividing two classes into a feature space. This plane is usually described by a linear equation (linear discriminant function) together with b(i) parameters, which can be approximated by the method of minimum squares in terms of arithmetic features:

$$b_i = (X - M)^{-1} \times S$$

where X is the matrix of initial data; M is the vector of average values for features; S is the covariation matrix of features.

A linear discriminant function may be considered as a diagnostic model for identification of landscapes. There exists an algorithm for searching linear discriminant functions of the binary scale (Andreev, 1981), that has been applied in a given case.

Diagnostics of new objects by a linear discriminant function is carried out with the help of the above equation for the values of their features and the calculation of the L value. When $L > 0$, the object may belong to class I, in other cases, it belongs to class II.

4.7. Programmes for Data Processing

To solve the problems of automatic and diagnostic classification comprehensively, special packages and programs of software have been developed. They were subject to a detailed test for data processing in forestry, ecology, soil science and other disciplines. The PEDOCLAS and TAXON programs have a wide application. Algorithms used were also programmes dealing with specific databases directly connected with GIS ARC/INFO. These programmes allow a researcher to use data directly from a data base and different layers of maps in a dialogue form. The available information system permits to improve and advance programs for the data processing. Figure 4.2 demonstrates the full list of tasks which can be solved by the methods of numerical taxonomy. The concept of enumeration classification, used in this study for the formalisation of a landscape design allows to solve many other tasks.

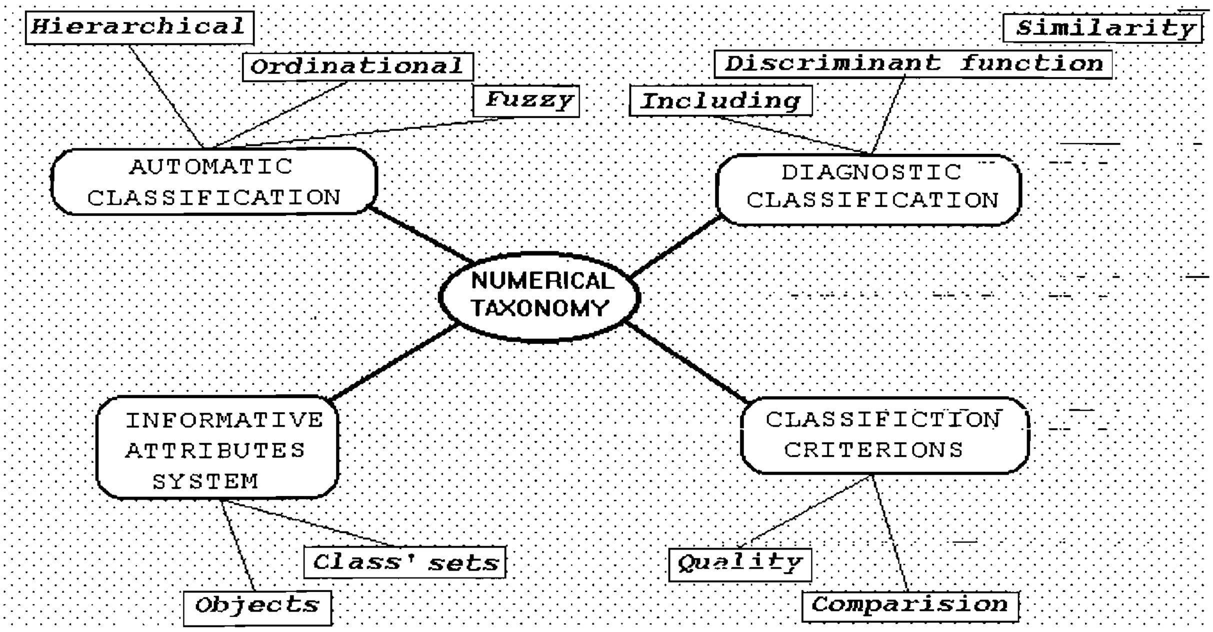


Figure 4.2. List of numerical taxonomy tasks

5. Cartographic Approach

A cartographic illustration of the enumerative landscapes makes it possible to visualize the basic concept. An example on how the cartographic classification of the enumeration takes place is shown in Figure 5.1. The classification of unique combinations of contours results from overlaying maps of the parameters defined in terms of a natural area complex (NAC).

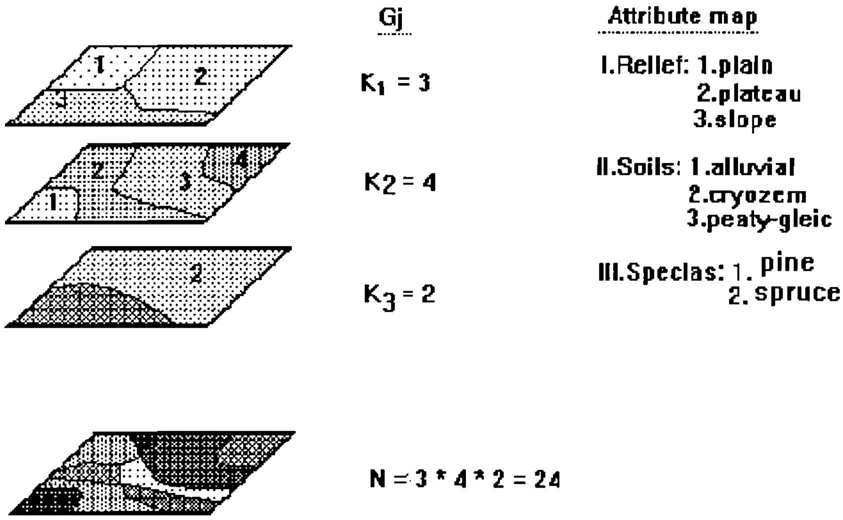


Figure 5.1. Cartographic representation of the enumerative landscapes

The system of obtained contours characterizes the full diversity of the conditions of an area. It should be noted, that the suggested constructions are formalizations of the traditional approaches for landscape identification, making complex interpretation of maps possible.

The basic maps for this study are based on earlier compiled maps of natural area complexes. They were produced in the scale of 1:1 million. The highlighted NAC (below, this term and the term "landscape" are regarded as synonyms) represent parts of ecoregions. Therefore, two neighboring NACs, located in different administrative oblasts (and, hence, in different ecoregions), may be completely identical.

Gudilin's map legend and other maps were used in the cartographic approach. Figure 5.2 shows the list and the layers of enumerated maps, that were used in the study.

The first task of this approach was to transfer the contours of the basic NAC paper maps to the Digital Chart of the World (DCW).

The basic maps are of the scale of 1:1 million (except for Antarctica, where the scale is reduced to 1:2 million). This is the largest scale unclassified map series that provides consistent, continuous global coverage of essential basic features. It is composed of 17 thematic vector layers, which include political boundaries, coastlines, cities, transportation networks, hydrology, landcover, hypsography, and names of places. The absolute accuracy of the DCW vector information is 2000 m of circular error (horizontal) and ± 650 m of linear error (vertical) for the contours. The vertical accuracy for the spot heights is ± 30 m. The accuracies are within the 90-percent confidence interval as defined by the US Defense Mapping Agency.

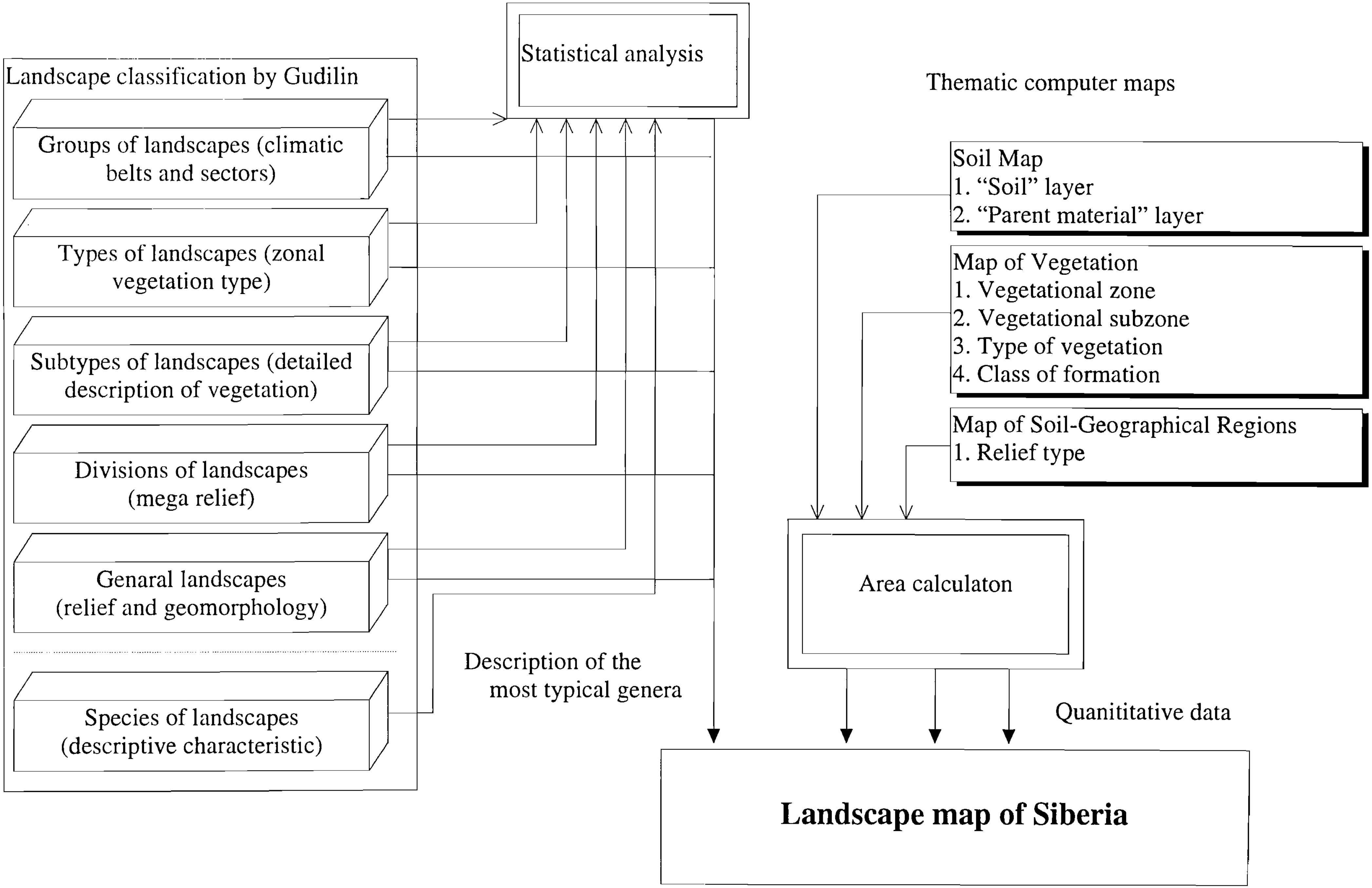
The descriptions of the Landscape Map (edited by I. S. Gudilin, 1987) has served as the database for the landscape classification. The original NAC's are essentially larger than the contours, corresponding to genera and especially to species of landscapes of the Gudilin

(1987) map. Therefore the descriptions of the Landscape Map were used for the unified explanation of the original contours. In order to process and generalize the indices of species contours, in particularly by implementation of formal methods, they were itemized as they belonged to the specified NAC contours.

Vegetation appears to be the most complicated and controversial component of the NAC description. The Vegetation Map (Belov, 1989) was used to adjust this layer. In addition, the earlier developed database on soils of Siberia (Roshkov, 1996), was implemented. Thus, the soil component of the Landscape Map was updated, adding another 13000 contours broken down by contours of the NACs.

Furthermore, new information on mineralogy of deposits and soils of landscapes was added. Finally, information on wild animals of the NACs was attached.

Figure 5.2. Scheme for the landscape map generation



6. Resulting Map and Numerical Classification of Siberian Landscapes

6.1. Design of the Landscape Map

The computerised map of the Siberian landscapes contains 347 contours. According to Gudilin, the contours can not be regarded as basic landscapes or typological units of a landscape classification. They are rather units of a landscape regionalization, and the map thus is a map of landscape regions. The map composed by Gudilin himself for the same territory in the scale of 1:2,5 million contains 4520 contours referring to more than 1700 landscapes.

The current map legend contains the following information:

1. Original name of the landscape

The name is given in the form of geographical names and usually includes some physical-geographical characteristics. For example, "Het-Popigai plain landscape with undershrub-moss tundra".

2. Landscape characteristics according to Gudilin's classification at the level of genera.

It includes the following classification levels:

a. Group - determined by macroclimatic features (zones, sectors).

b. Class - determined by zonal vegetation type.

c. Subclass - determined by a more detailed vegetational description, including altitude belts and azonal/intrazonal associations.

d. Division - determined by megarelief and tectonic regimes.

Four divisions are determined: 1. Plain-platform landscapes; 2. Landscapes of inter-platform mountains; 3. Landscapes of piedmonts and intermountain plains (plains within folded belts); 4. Folded and blocky-folded landscapes.

e. Genera - determined by relief type and prevailing geomorphological processes.

As a rule, 10-20 contours of the Gudilin map are united within one contour of our map and they refer to 5-6 different genera. Thus, in order to describe a contour at a genera level, holotypes were calculated. To calculate holotypes, the information at the level of Gudilin's species was used. (In a given classification, this level has no unified classification. Every species is characterised by a text description, containing the details of the features with the objective to distinguish higher classification levels, and by the description of features that were not regarded at the higher classification levels). For every contour, the most typical species - holotypes - were determined, and their description at genera level was used to characterise the contours. It is obvious that the characterisation of a contour of a map at species level does not make any sense due to great internal diversity of the contours.

3. Soil Characterisation

To describe the soils of the landscape contours, Soil Maps of Russia in the scales of 1:2.5 million, 1:4 million and 1:8 million, were used.

Every contour contains a set of soils, classified according to a unified map legend. The percent of contour area occupied by a given soil is also listed.

4. Characterisation of Parent Materials

The information about parent materials was obtained from the soil maps, as well as from the Map of Soil-Geographical Regions. For every type of parent materials, the percent of area occupied within a contour, was calculated.

5. Characterisation of Vegetation

In addition to the vegetation description included in the landscape classification at class and subclass level, the set of plant communities is represented for each contour. The percent of area occupied by each community within a contour is listed. The information was obtained from the Map of Vegetation of the USSR constructed in the scale of 1:4 million (Belov, 1989). The description of the plant communities includes:

1. Vegetation type
2. Vegetation zone
3. Subzone
4. Community name with enumerated indicative species
5. Information about altitude

6. Characterisation of the Degree of Diversity

The estimation of landscape diversity can be made at each level, including the facie level, but it demands a more detailed information compared to that used to obtain the contours.

To estimate the diversity of the natural conditions within the contours of our map, it was sufficient to use the Landscape Map by Gudilin, as 10-20 landscape species can be found within each contour.

The following diversity criteria can be used:

(a) the coefficient of holotype typicality;

(b) the bottom-up likelihood level obtained at the construction of species dendrograms within a contour with the help of hierarchical cluster analysis;

(c) the level of inter-group likelihood, at the construction of dendrographs with the help of the cluster analysis.

We found that, at the numerical classification of the contours of our map based on the information obtained from the map by Gudilin, the level of inter-group likelihood is usually lower than that between groups. This means that the differences among landscape species within a contour are bigger than between two neighbouring contours.

6.2. Numerical Classification--Hierarchical Models

Two types of structural models for the Siberian landscape diversity were used: dendrograms and dendrographs. Dendrograms reflect a set of individual landscapes as a likelihood tree. Dendrographs reflect the likelihood among object classes.

In our case, individual landscapes are represented by the holotypes of Gudilin's landscape species within the contours of Natural Area Complexes (NAC). The complexes were determined at previous stages of the Siberian Forest Study. The diversity of species in a given NAC forms a class where an average inter-class likelihood among species can be determined. The likelihood among different classes (different NACs) can be calculated by an average likelihood of their components - species. It is evident that dendrograph calculation provides additional information about NAC heterogeneity and provides a more statistically reliable estimation of the likelihood among them.

Landscape likelihood, determined at the calculation of dendrograms and dendrographs, is a system-designing element providing the possibility to examine landscapes as a system. Emergent properties are represented by a hierarchical structure, which is visualised as a tree.

Let us stress some advantages of the application of the numerical classification of the analyses of the landscape structure of the Siberian territory: (1) The NACs, described by different authors, following different principles, are described in a unified space of characters. (2) Formalised description provides the possibility for mathematical treatments, estimations, comparisons, and visualisation. (3) A new classification system with new properties and structure can be created, making it possible to optimise NAC descriptions and the landscape diagnostics.

The list of initial 347 NACs is presented in Appendix 2.; a set of 68 features (attributes, characteristics), were used for further analyses, which is discussed in the following section.

The amount of dendrograms and dendrographs of NACs is rather large for visual analysis. They can be interpreted with respect to different aspects, depending on the tasks. This kind of analysis was not planned for the current stage of work. So, only the most general questions will be discussed below.

The dendrogram of landscape holotypes differs much from their dendrograph. Mutual conjugation of these two structures, determined according to Sokal and Rolhf (1962), is significant from a statistical point of view, but with a quite low coefficient of correlation is (0.45). The dendrograph reflects clearly the heterogeneity of distinguished NACs. It is demonstrated via a brush-like form of a likelihood tree and with relatively low values of the likelihood. The average holotype likelihood was 53%. An average value of likelihood among NAC groups was the same. Average inter-group likelihood of landscapes was about 70%, differing from the likelihood among groups only by 17%. This is another indication of the NAC heterogeneity. It means that the division of landscape should be further detailed in order to determine more homogeneous NACs.

Further analysis of constructed dendrograms and dendrographs will be conducted with the help of an optimised set of attributes serving for the landscape description.

6.3. Choice of Informative Attributes

The initial total attributes, which were used for the landscape description, included the values in nominal, binary, range, and arithmetic scales. Nominal features are not abundant, so they were not used in the mathematical analysis. The list and description of the used 68 attributes is given in Table 6.1.

It is evident that the landscapes are described by various combinations of attributes. Transforming the matrix of initial descriptions (i.e. going from the table "object-properties" to the table "property-objects") gives a possibility to construct a dendrogram of landscape attributes. The dendrogram is presented in Figure 6.1. As a result, there is a possibility to estimate the conjugation of landscape attributes despite different scales of the attached values.

The dendrogram demonstrates that some features are alike at a high level, even at the 100% level. Such a high conjugation indicates that a landscape description was excessive, and it is possible to exclude the attributes with limited value of information. The rule is the following: only one character is left from the group of highly conjugated characters. The procedure for the choice of this indicator remains subjective, however, this is not crucial given the amount of information available. Furthermore, there are no limitations for a subjective choice of the most important features.

In our case, 29 characters were excluded from the whole set. The remaining set included 39 attributes, which is 43% less than in the initial set. Table 6.1 contains the list of rejected and remaining features. The permitability of this rejection can be estimated statistically. The permitability is calculated by comparing dendrograms and/or dendrographs constructed by a full respectively a reduced character set. A high conjugation should denote the possibility to decrease the list of characters.

In this case, the dendrograms had a correlation coefficient of 0.62 in both cases, the reduction had almost no effect on the dendrographs, and the correlation was 0.91. In addition, it did not influence the likelihood among and inside groups. In fact, it remained the same:

51% instead of 53% for the dendrogram and 52% instead of 54% for the dendrograph. Inter-group likelihood became 69% instead of 70%.

So, a reduction of the number of characters by 43%, designed for landscape description, did not lead to significant losses of information. Thus, 39 characters could be used instead of 68. Further analysis of the landscape structure of Siberia can be conducted based on the reduced set .

Mean likelihood values among and inside groups of landscapes and NACs can serve as indicators of diversity. Likelihood values are coequivalent to biodiversity indices: the lower the likelihood is, the higher is the possible diversity.

6.4. Cartographic Representation of Classifications

Big dendrograms are not comfortable for visualisation. A more convenient way is a cartographic representation of these classification structures. For this purpose, the dendrogram and/or dendrograph is dissected at different levels. Obtained typological classes are transmitted to initial cartographic forms by colouring or shading. The higher the likelihood level of dissection is, the more classes are distinguished. However, the classes can also be distinguished by the clusters of the dendrogram branches. Cartographic representation of this kind was made for the dendrograms and dendrographs constructed by the reduced set of attributes (Figure 6.2-6.4).

Table 6.1. List of landscape attributes

Attribute name	Usage in final clasification	Scale	Description
BELT	used	Rank	Climatic belt
SECTOR	used	Rank	Climatic sector
PACIFIC	used	Binary	Is this sector sub-atlantic or sub-pacific
ALTITUDE	used	Rank	Altitude level
ZONE	used	Rank	Vegetation zone
VEGET-TYPE	used	Rank	Vegetation type, sorted according to living phytomass from tundra and deserts to forests
D1	excluded	Binary	Platform or folded area
D2	used	Binary	Plain or mountain
PROCESS	used	Rank	Main geomorphological process
STRUCTURE	used	Rank	Relation between endogenic rocks and sediments
EFF-INTR	used	Rank	Relation between effusive and intrusive rocks
EXOGEN	used	Rank	Influence level of exogenic porcesses
SORT	used	Rank	Degree of sorted parent material (from eluvium and moranic to sea deposits)
CHIM	used	Rank	Chemical classes of sediments
Percentage of relief types			
REL1	used	Quantitive	Plains
REL2	used	Quantitive	Plateaus

REL3	excluded	Quantitive	Hills
REL4	excluded	Quantitive	Piedmonts
REL5	excluded	Quantitive	Low mountains
REL6	excluded	Quantitive	Middle mountains
REL7	used	Quantitive	Mountains (in general)
REL8	used	Quantitive	Reliefs, created by water flows
REL9	excluded	Quantitive	Bogs
REL10	excluded	Quantitive	Internal mountain plains
Percentage of vegetation types			
VEGET1	excluded	Quantitive	Arctic deserts
VEGET2	used	Quantitive	Tundras
VEGET3	used	Quantitive	Open forests
VEGET4	used	Quantitive	Creeping stands
VEGET5	excluded	Quantitive	Shrub thickets
VEGET6	excluded	Quantitive	Low shrubs thickets
VEGET7	used	Quantitive	Forests
VEGET8	used	Quantitive	Meadows
VEGET9	excluded	Quantitive	Steppes
VEGET10	excluded	Quantitive	Deserts
VEGET11	used	Quantitive	Bogs
Presence of tree species			
FOR1	excluded	Quantitive	spruce
FOR2	excluded	Quantitive	cedar
FOR3	used	Quantitive	pine
FOR4	used	Quantitive	larch
FOR5	used	Quantitive	birch
FOR6	excluded	Quantitive	aspen
FOR7	excluded	Quantitive	alder
FOR8	excluded	Quantitive	dark coniferous (spruce),
FOR9	used	Quantitive	light coniferous (pine, larch)
FOR10	used	Quantitive	mixed coniferous
FOR11	excluded	Quantitive	dark coniferous + deciduous
FOR12	used	Quantitive	light coniferous + deciduous
FOR13	excluded	Quantitive	coniferous + broad-leaved
FOR14	excluded	Quantitive	deciduous
FOR15	excluded	Quantitive	broad-leaved (oak, lime etc.)
FOR16	excluded	Quantitive	cedar + other coniferous
FOR17	excluded	Quantitive	fur + other coniferous
Presence of grass species			
HERB1	used	Quantitive	Mosses
HERB2	excluded	Quantitive	Sphagnum
HERB3	used	Quantitive	Lichens
HERB4	used	Quantitive	Undershrubs
HERB5	used	Quantitive	Bushes

HERB6	used	Quantitive	Cereals
HERB7	used	Quantitive	Herbs
HERB8	used	Quantitive	Small-leaved herbs
HERB9	excluded	Quantitive	Broad-leaved herbs
HERB10	excluded	Quantitive	
HERB11	excluded	Quantitive	
HERB12	used	Quantitive	Carex
HERB13	excluded	Quantitive	Xerophytic undershrubs
HERB14	excluded	Quantitive	Vegetation of salinized areas
HERB15	excluded	Quantitive	
HERB16	excluded	Quantitive	

The cartographic representation is made of the section of a dendrogram at given likelihood levels. The section results in the appearance of NAC classes (clusters), which are represented on the map by shading. The analysis is conducted by a reduced set of characteristics. The choice of section level was made by experts in our case. However, in principle, it is possible to optimise this solution by using some quality criterion. Its formulation demands to make the optimisation goals more concrete. In this case, only the major possibilities are presented.

The first section of the dendrogram of landscape holotypes was made at the likelihood level of 77%. The cartographic representation of the section (visualisation) is presented in Figure 6.2. Eight big NAC's were distinguished. They represent the generalisation of initial landscapes at genera level. The obtained division is very close to the division of the Siberian territory into landscape regions. The territory of West Siberia formed clearly a relatively homogeneous NAC. East Siberia is also, quite clearly, distinguished despite a more pronounced NAC variability. The Far East is the most heterogeneous. This is a result of the variation of the natural conditions in this vast territory.

This NAC regionalization (a macro-regionalization) reflects the current understanding of the zonal and sectoral differentiation of the Siberian territory. The zone of tundra landscapes is detected , and the internal differentiation was found as well. For the rest of the territory, where sector division is present, the mountain regions were detectable.

The section of holotype dendrogram at the likelihood level of 89% gives a much more detailed picture (Figure 6.3). This level was chosen by experts in order to illustrate a general approach for the analysis. In a concrete case, the formulation of goals and corresponding criterion of the division is needed.

In East Siberia, the NAC's of Ob and Irtysh valleys appear. The map of the mountainous Sayan-Altai region has a mixed and complex character. East Siberia and the Far East are divided into a range of NAC's. In total, 34 NAC's are distinguished.

Thus, the cartographic representation of the section of holotype dendrograms reflects the existing understanding of the landscape differentiation of the Siberian territory. An advantage of this applied approach is, first of all, a unified database for landscape classification, that does not depend on subjective viewpoints of different scientific schools, and is based on quantitative indices of likelihood and homogeneity of landscapes and other NAC's. It is possible to optimise the division of the territory by using different criteria and varying the set and values of attributes used for the landscape description. By combining attribute sets obtained from the database, it is possible to construct different patterns of the regionalization of the territory and give a quantitative estimation of the mutual conjugation and relation to other types of cartographic regionalization.

It is evident that the used hierarchical model and its cartographic interpretation provides great possibilities for analyses and construction of classification systems. In addition, schematic constructions are possible. One of them is illustrated by studying the NAC dendrograph. Figure 6.4. demonstrates a cartographic representation of 7 classes of NAC's distinguished by the dendrograph of the reduced information system of characteristics. In this case, not the section, but a visual determination of classes was made. The picture is less determined than in the case of holotypes. However, no deviations of reasonable understanding can be found. The special character of West Siberia is demonstrated, mountainous NAC's of Altai, Sayan, Transbaikalian and Pre-Amur territories, Northeast, and Sakhalin are detectable. The differentiation of other parts of East Siberia and the Far East is more detailed than at the level of physical-geographical regions (sector division), however, it reflects the zonal differentiation to a less extent.

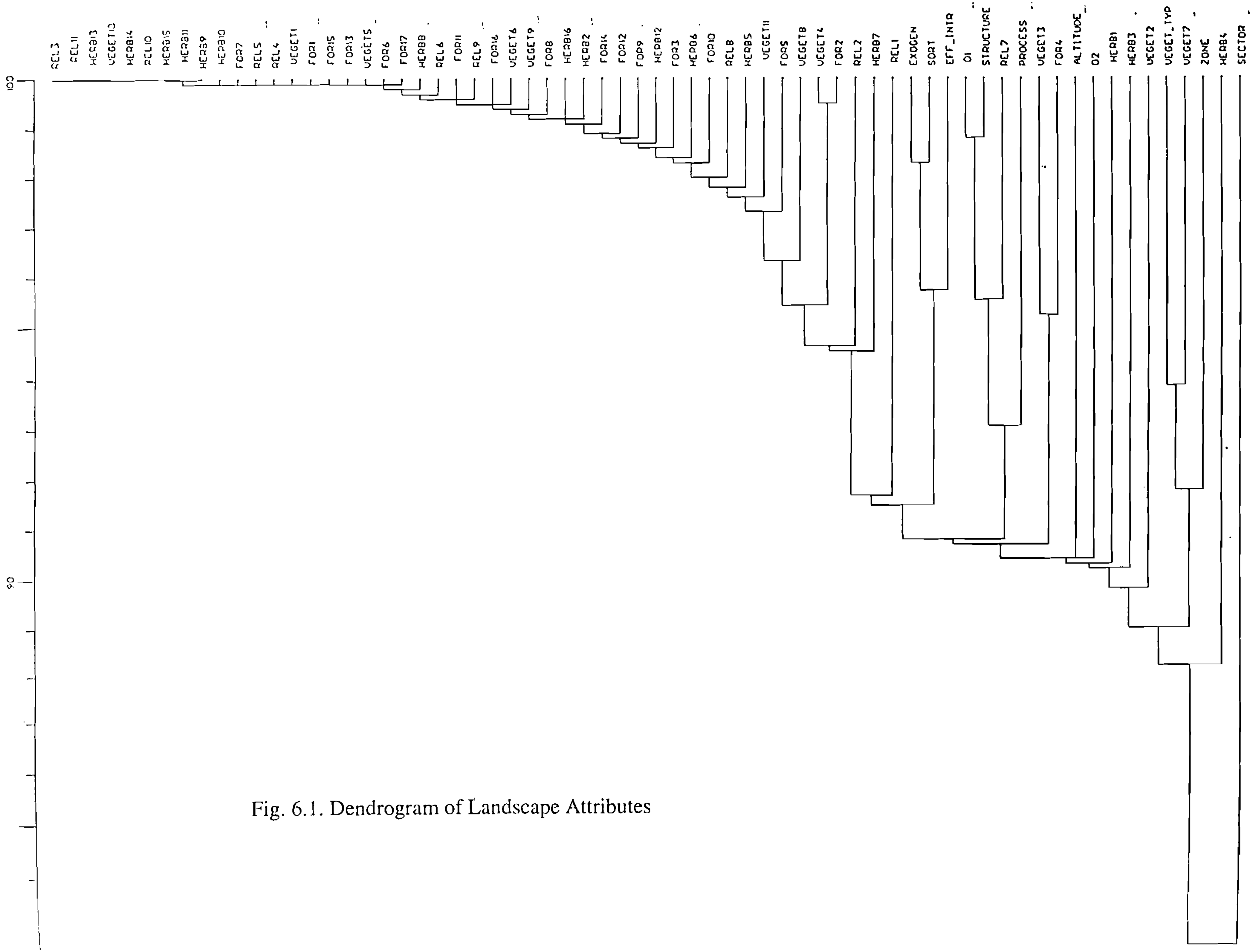


Fig. 6.1. Dendrogram of Landscape Attributes

Fig. 6.2. Numerical classification of landscapes
Similarity level 77%

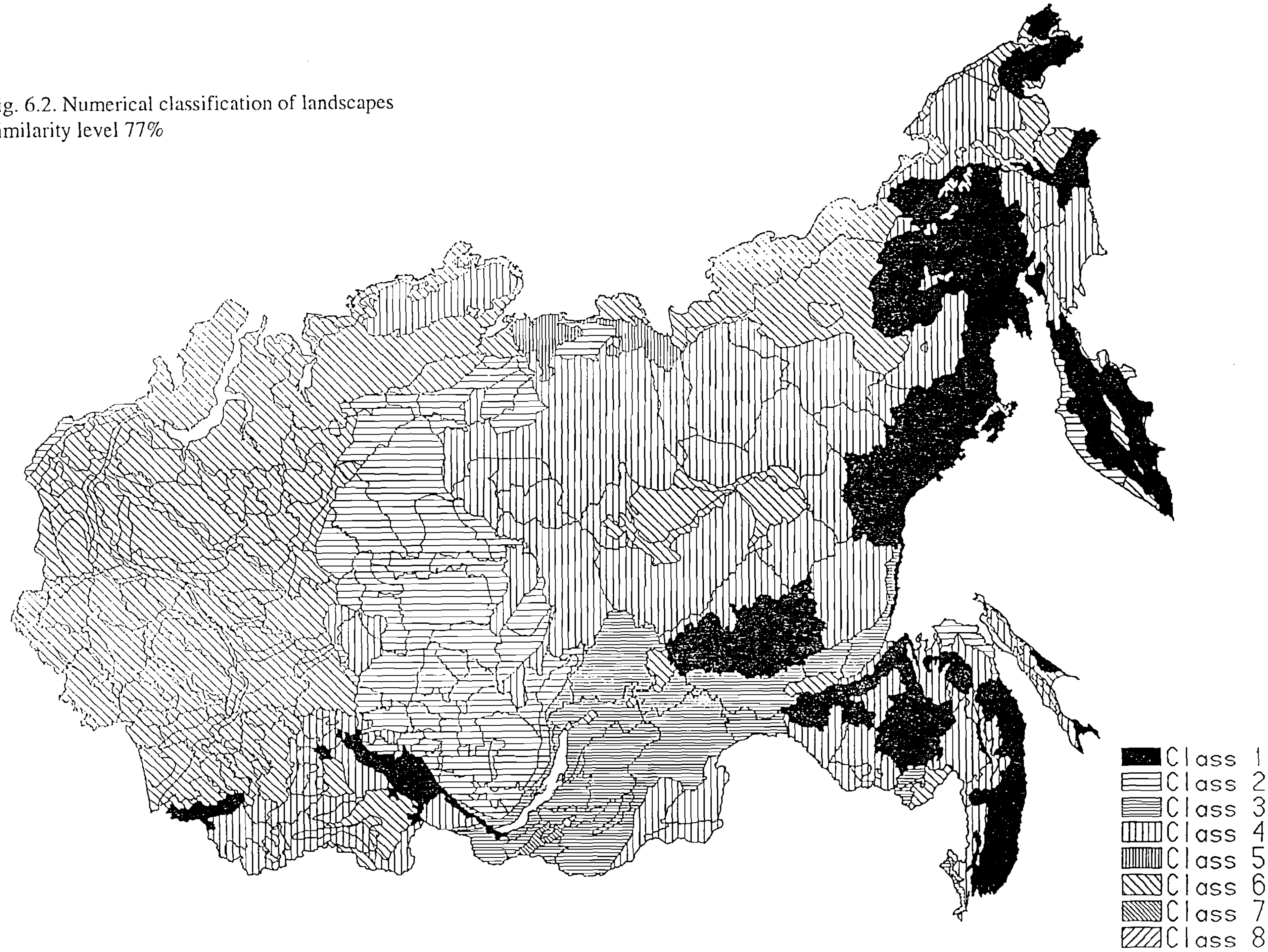


Fig. 6.3. Numerical classification of landscapes
Similarity level 88%

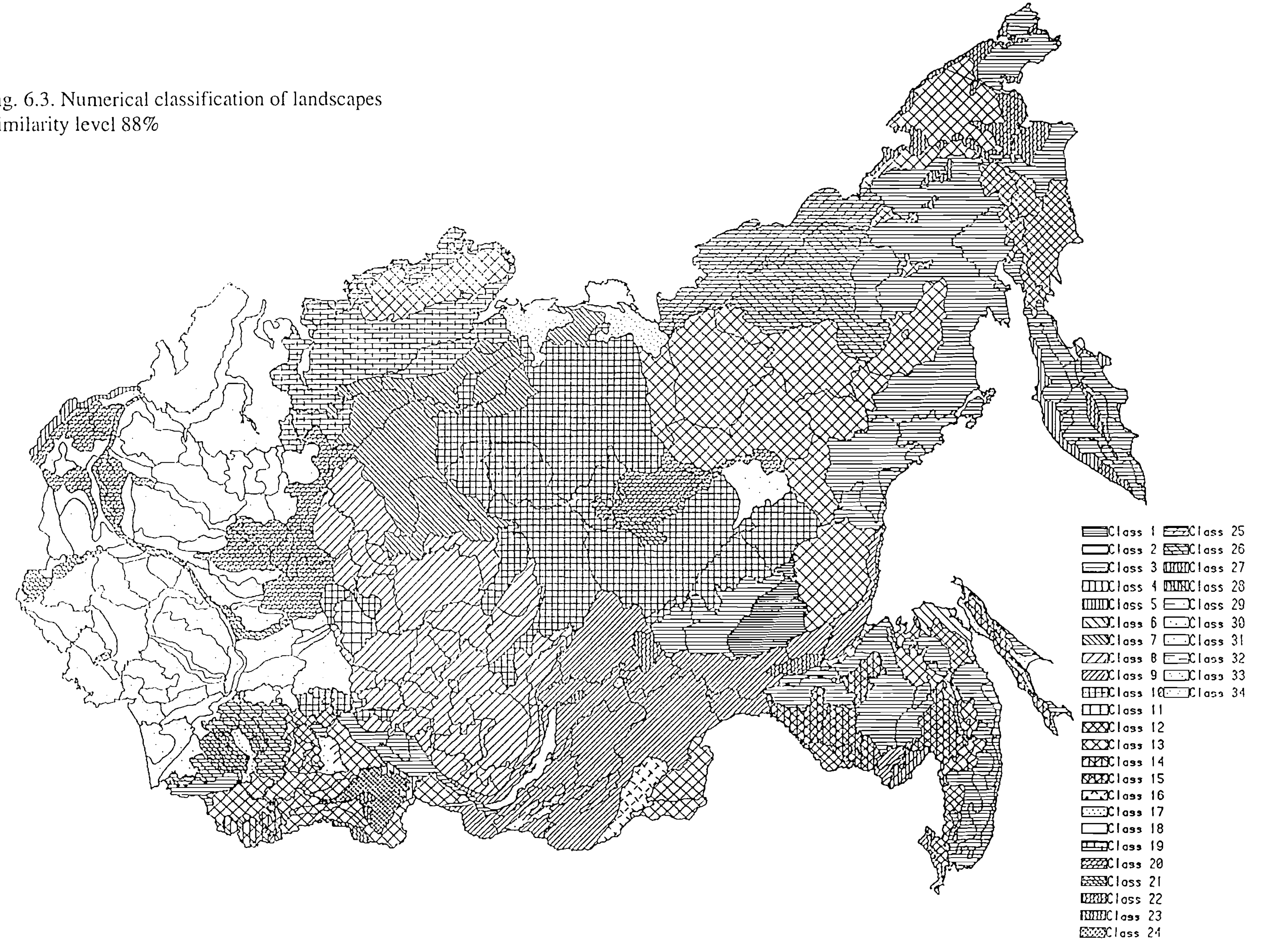
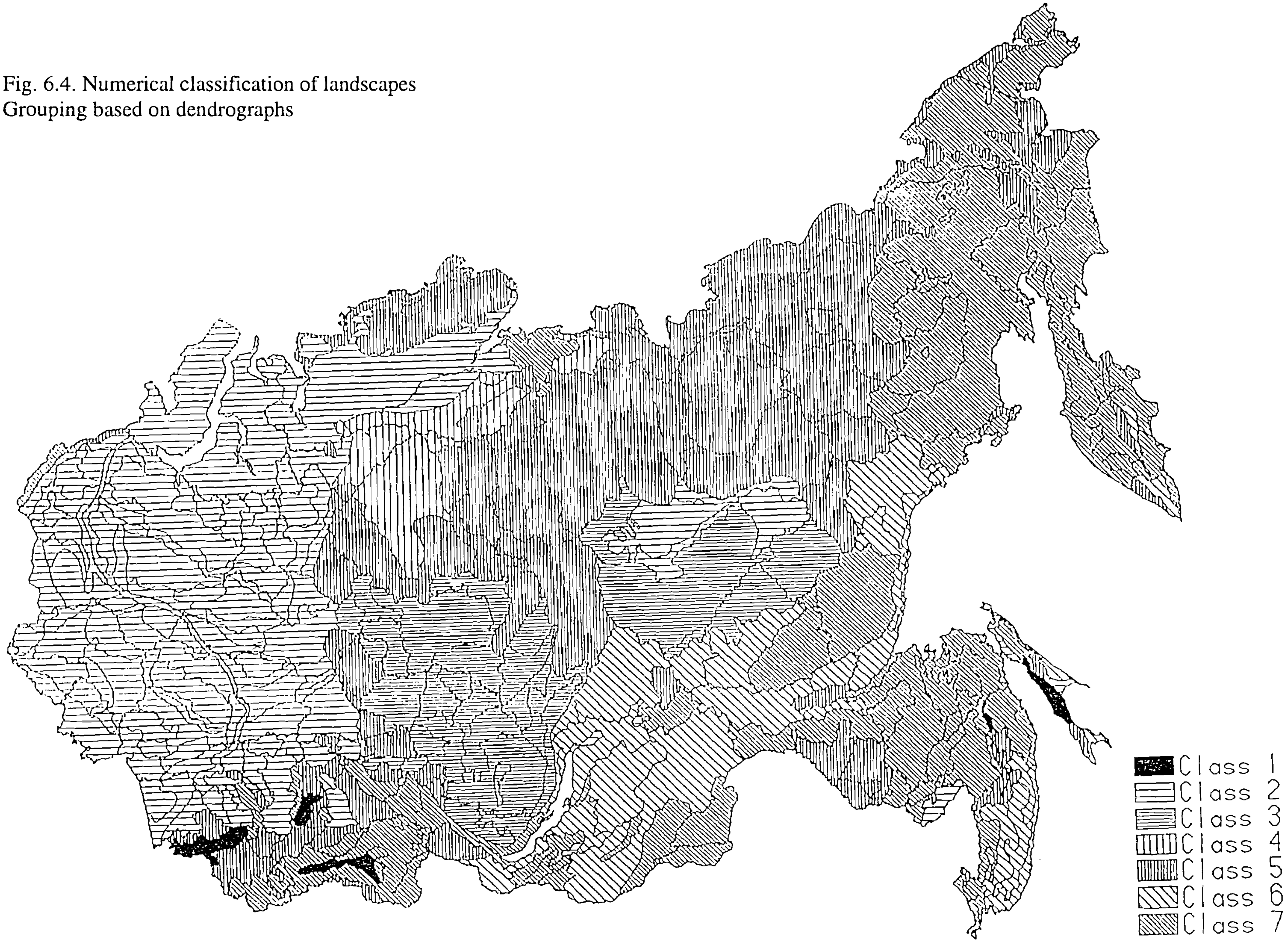


Fig. 6.4. Numerical classification of landscapes
Grouping based on dendrographs



7. Conclusion

A formalised landscape description allowed us to represent Siberian NACs, determined by different authors, in a unified data space. By using mathematical methods, hierarchical classifications of the NACs could be constructed. The classifications, based on holotypes and species-genera characteristics of landscapes were visualised as hierarchical trees, dendrograms, and dendrographs. A system of informative characters was determined. It includes 43 % characters less than the initial set of characters for the landscapes. Calculated values of likelihood inside and between groups indicate the diversity.

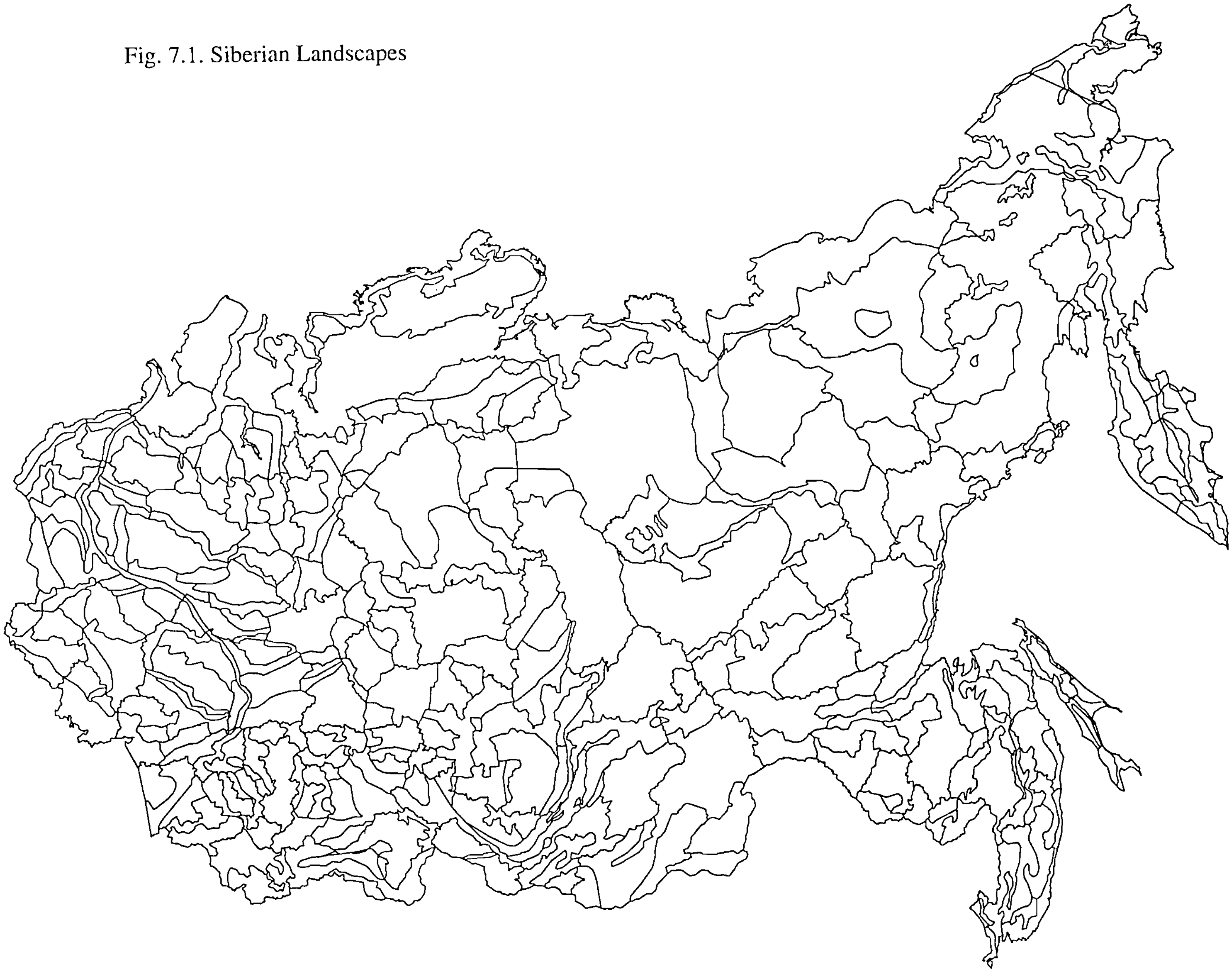
The cartographic representation of the section of holotype dendrogram reflects the existing understanding of the landscape differentiation of the Siberian territory. An advantage of the applied approach is, first of all, a unified (independent of subjective opinions of various scientific schools) database of landscape classifications and quantitative indices of likelihood and heterogeneity of landscapes and other NAC's. By the approach, it is possible to optimise the division of the territory by formulating different criteria and by varying the composition and values of the attributes used for the landscape description. By varying the attribute sets obtained from the database, it is possible to create various patterns of the territory regionalization and to give a quantitative estimation of the interrelations and connection to other types of cartographic regionalization.

The analyses of obtained data and classifications lead to the conclusion of a substantial heterogeneity of NAC's. In order to apply the landscape approach for forecasting of the forest dynamics, forest productivity and biodiversity, the landscape structure of the territory should probably be even further divided. More homogeneous landscapes (by species-genera characteristics).

The conducted work resulted in the creation of an automatic attributive cartographic classification system, which includes the database of characteristics designed for landscape descriptions, the methods for creation and support of cartographic presentations, and the algorithms for analysis of landscapes.

The current identifying set of large scale landscapes (or "landscape types" or "regions"), based on the analyses, and currently employed by IIASA's Siberian Forest Study, is presented in Figure 7.1.

Fig. 7.1. Siberian Landscapes



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Appendix 1

Landscape Attributes

The Characteristics of Landsapes (by Gudilin)

Initial description of the landscapes was provided by using the characteristics listed below. In order to conduct statistical analysis, each character was transformed into several scales, represented as independent fields. At the first stage, the whole set of landscapes was structuralized according to Gudilin, who used several hierarchical levels: group, type, subtype, division, genera.

1. GROUP - includes the landscapes with similar macroclimatic characteristics. Describes climatic belt and continentality. (It should be noted that the order of the codes is not same as the order of the classification items) Initial classes:

1 Arctic
2 Boreal continental
3 Boreal oceanic (pacific)
4 Boreal suboceanic(atlantic)
5 Boreal suboceanic (pacific)
6 Boreal severe continental
7 Boreal moderate continental
8 Subarctic suboceanic and oceanic (pacific)
9 Subarctic severe continental
10 Subarctic moderate continental and continental
11 Subboreal continental
12 Subboreal suboceanic (atlantic)
13 Subboreal suboceanic (pacific)
14 Subboreal severe continental
15 Subboreal moderate continental
16 Subtropical continental
17 Subtropical suboceanic (atlantic)
18 Subtropical moderate continental

For the statistical treatment, the GROUP character was divided into 3 fields:

1. Climatic belts (rank scale) BELT

1 - arctic
2 - subarctic
3 - boreal
4 - subboreal
5 - subtropical

2. Sectors, or continentality (rank scale) SECTOR

1 - oceanic
2 - suboceanic
3 - moderate continental
4 - continental
5 - very continental

3. Location near the ocean (nominal scale) PACIFIC

0 - continental
1 - Atlantic
2 - Pacific

2. TYPES AND SUBTYPES unite the landscapes with similar vegetation cover. Describes primarily vegetation type.

Landscape TYPES:

1. Arctic (polar) deserts
2. Arctic tundra
33. Subarctic tundra
28. Forest tundra
35. Taiga forests
29. Decidouis forests and meadows
36. Broad leaved forests
37. Broad leaved liana forests
27. Forest-steppe
32. Steppe
30. Semideserts
31. Deserts
34. Subnival landscapes
26. Mountain cold deserts
4. Mountain arctic (polar) deserts
5. Mountain arctic tundra
22. Mountain tundra
23. Mountain tundra and steppe
24. Mountain tundra and subtundra sparsed forests
25. Mountain tundra and elvinwood
11. Mountain meadows (subalpic and alpic)
12. Mountain meadows (subalpic)
10. Mountain meadows
13. Mountain meadow steppes (alpic and subalpic)
14. Mountain meadow steppes (subalpic and alpic)
15. Mountain meadow steppes and exposition-dependent forests
6. Mountain forests (mixed coniferouis and broad-leaved)
7. Mountain forests (broad-leaved and mixed)
8. Mountain forests (broad-leaved)
9. Mountain forest-steppes
16. Mountain decidous forests and elvinwoods
17. Mountain sparsed forests
18. Mountain sparsed forests and elvinwood
19. Mountain steppes
20. Mountain steppes and deserts
21. Mountain taiga forests
3. Mountain deserts, steppe and xerophite sparsed forests

SUBTYPES of landscapes:

1 Arctic desert low mountains
2 Arctic tundra low mountains
3 Tundra-bare top uplands
4 Tundra-bare top middle mountains
5 Bare top uplands
6 Tundra-bare top uplands
7 Stony subnival uplands
8 Suppressed and deformed forests and elfin wood
9 Xerophytic bushes and sparced forests of middle and high mountains

10 Forested low mountains (with mediterrannian forests)
11 Forested low mountains (with mixed broadleaved and coniferous and deciduous forests)
12 Forested low mountains(with mixed broadleaved and coniferous forests)
13 Forested low mountains (with broadleaved forests with evergreen understory)
14 Forested low mountains (with broadleaved forests)
15 Forested low and middle mountains(with broadleaved forests)
16 Forested middle mountains (with mixed broadleaved and coniferous forests)
17 Forested middle mountains (with coniferous and mixed broadleaved and coniferous forests)
18 Forested middle and low mountains (with broadleaved and broadleaved and coniferous forests)
19 Forest steppe low mountains
20 Meadow-forest and forest-meadow-steppe low mountains (with coniferous, deciduous and broadleaved forests)
21 Meadow-forest and forest-meadow-steppe middle mountains (with coniferous, deciduous and broadleaved forests)
22 Meadow-forest and forest-meadow-steppe middle mountains and uplands (with broadleaved forests)
23 Meadow-forested low mountains (with coniferous and broadleaved forests)
24 Meadow-steppe uplands
25 Meadow-steppe and steppe uplands
26 Meadow-tundra middle mountans
27 Meadow uplands
28 Meadow and meadow-steppe uplands
29 Meadow and tundra-meadow middle mountains
30 Meadow low mountains
31 Meadow middle mountains
32 Low mountains with deciduous forests
33 Low mountains with exposition-dependent forests
34 Subtaiga (with mixed deciduous and coniferous and deciduous forests)
35 Subtaiga (with mixed deciduous and coniferous forests)
36 Subtaiga (with mixed deciduous, broadleaved, and coniferous forests)
37 Subtaiga (with mixed broadleaved and coniferous forests)
38 Pre-tundra sparced foests
39 Desert-steppe uplands
40 Desert-steppe low mountains
41 Desert-steppe middle mountains
42 Desert-tundra middle mountains
43 Desert uplands
44 Sparced forests and tundra-elfin wood low mountains
45 Sparced forests and tundra-elfin wood middle mountains
46 Sparce taiga low mountains
47 Sparce taiga middle mountains
48 Tundra-sparced forest low mountains
49 Tundra-sparced forest middle mountains
50 Sparced forest low mountains
51 Sparced forest and tundra-sparced forest low mountains
52 Northern desert
53 Northern taiga
54 Northern tundra
55 Middle and southern taiga
56 Middle taiga

57 Steppe (semi-savanna) low mountains
58 Steppe and desert-steppe middle mountains
59 Steppe low mountains
60 Elfin wood and sparced taiga low mountains
61 Elfin wood and sparced taiga low mountains
62 Elfin wood-tundra low mountains
63 Elfin wood-tundra middle mountains
64 Elfin wood and tundra-elfin wood low mountains
65 Elfin wood low mountains
66 Dry steppes
67 Taiga and sparced taiga middle mountains
68 Taiga low mountains
69 Taiga middle mountains
70 Typical (true) steppes
71 Tundra-steppe and steppe uplands
72 Tundra uplands
73 Tundra and bare top-tundra uplands
74 Tundra and sparced forest-tundra uplands
75 Tundra low mountains
76 Tundra and sparced forest low mountains
77 "Shiblyak" low mountains
78 Southern desert
79 Southern taiga
80 Southern tundra

The statistical description of TYPES AND SUBTYPES includes 3 fields:

1. Altitude level (rank sacle) ALTITUDE
   1 - plains
   2 - low mountains
   3 - middle mountains
   4 - high mountains

2. Climatic zones (rank scale) ZONE
   1 - arctic deserts, vegetation-less (bare) tops ("goltsy")
   2 - tundra and elfin woods
   3 - meadow/tundra, forest/tundra, steppe/tundra, sparced forests
   4 - taiga
   5 - mixed forests
   6 - broad-leaved forests
   7 - meadows
   8 - forest steppes
   9 - steppes
   10 - semideserts
   11 - deserts

3. Vegetation types (rank scale) VEGET-TYPE
   1 - deserts (incl. arctic deserts)
   2 - semideserts, tundra
   3 - sparced forests, elfin woods
   4 - forest/tundra, steppes, meadows
   5 - forest steppes
   6 - taiga, mixed forests

7 - broad-leaved forests

Landscape DIVISION unites the landscapes with the same geological megastructures.
There are four classes

Mountain belts:
1. Mountains
2. Piedmonts and interridge plains

Platforms:
3. Mountains inside platform
4 Plains

Statistical description of DIVISIONS includes 2 fields:

1. Megarelief (field D1) (binary scale)
plains - 0
mountains - 1

2. "Tectonics" (field D2) (binary scale)
folded areas- 0
platforms - 1

Landscape GENERA unites the landscapes with similar genesis.
Describes morphosculptures and relief genesis:
Accumulative-denudational
Accumulative

2	Alluvial-proluvial
3	Alluvial
4	Bogs and marches
5	Fluvioglacial
6	Deltas
7	Deluvial-proluvial
25	Sea-glacial
26	Glacial
27	Glacial and fluvioglacial
28	Loess
29	Sea deposits
30	Lake-alluvial
31	Lake deposits
32	Mixed origin
33	Solontchaks
38	Eol deposits

Volcanogenic

8	Denudational-eroison
17	Denudational

Stratic plains

11	Denudational-eroison
20	Denudational

Structural

13	Denudational-eroison
22	Denudational

Trappes
14 Denudational-eroison
23 Denudational

Plains with hard rock base
15 Denudational-eroison
24 Denudational
37 Exaration (glacial erosion)

Volcanic
Mountain landscapes
1 Volcanes
34 Exaration

Volcanogenic
Stratic plains
12 Denudational-eroison
21 Denudational

Middle and high mountain
36 Exaration

Volcanoes
Mountain
16 Denudational-eroison and exaration

Flexure Block-flexure and blocked regions
Low mountains
18 Denudational

Low and middle mountains
9 Denudational-eroison

Various mountains
10 Denudational-eroison
19 Denudational
39 Erosion

Middle mountains
35 Exaration

For statistical analysis, the description of GENERA was transformed into 2 fields

1. Process type (nominal scale) PROCESS
   1 - accumulative
   2 - denudation and erosion
   3 - denudation
   4 - exaration

2. Ratio between plutogenic and sedimentary material (rank scale) STRUCTURE
   1 - accumulative plains
   2 - stratified plains

3 - plinth plains
4 - structural plains
5 - trapps, volcanogenic materials
6 - blocked, folded-block and folded areas

Numeric Representation of Landscape Characteristics

Numeric representation is another way to provide statistical analysis of presented data. The table consists of columns corresponding to character strings. Every column contains the percentage of a given type of a character within a contour.

VEGETATION TYPE

class	Vegetation	field name
1	Arctic deserts	VEGET1
2	Tundras	VEGET2
3	Open forests	VEGET3
4	Creeping stands	VEGET4
5	Shrub thickets	VEGET5
6	Low shrubs thickets	VEGET6
7	Forests	VEGET7
8	Meadows	VEGET8
9	Steppes	VEGET9
10	Deserts	VEGET10
11	Bogs	VEGET11

GRASS COVER types

class	Veget. cover type	field name
1	Mosses	HERB1
2	Sphagnum	HERB2
3	Lichens	HERB3
4	Undershrubs	HERB4
5	Bushes	HERB5
6	Cereals	HERB6
7	Herbs	HERB7
8	Small-leaved herbs	HERB8
9	Broad leaved herbs	HERB9
10	Stipal	HERB10
11	Artemisia	HERB11
12	Carex	HERB12
13	Xerophytic undershrubs	HERB13
14	Vegetation of salinized areas	HERB14
15	Rush	HERB15
16	Eriophorum	HERB16

TREE SPECIES

Code	species	field name
1	spruce	FOR1
2	cedar	FOR2
3	pine	FOR3
4	larch	FOR4
5	birch	FOR5
6	aspen	FOR6

7	alder	FOR7
8	dark coniferous (spruce)	FOR8
9	light coniferous (pine, larch)	FOR9
10	mixed coniferous	FOR10
11	dark coniferous + deciduous	FOR11
12	light coniferous + deciduous	FOR12
13	coniferous + broad-leaved	FOR13
14	deciduous	FOR14
15	broad-leaved (oak, lime etc.)	FOR15
16	cedar + other coniferous	FOR16
17	fir + other coniferous	FOR17

RELIEF

Relief	class description	field name
1	Plains	REL1
2	Plateau	REL2
3	Hills	REL3
4	Piedmonts	REL4
5	Low mountains	REL5
6	Middle mountains	REL6
7	Mountains (in general)	REL7
8	Relief,created by water flows	REL8
9	Bogs	REL9
10	Internal mountain plains	REL10

GENESIS OF THE MATERIALS is described by 4 scale fields, in the same way as for the landscape hierarchical units.

1. Genesis of solid materials (rank scale, field EFF_INTR)
   1 - effusive
   2 - intrusive
   3 - methamorphic

2. The role of exogenic processes in the material formation (rank scale, field EXOGEN)
   1 - massive and fresh volcanogenic materials
   2 - eluvial
   3 - eluvo-deluvial
   4 - deluvial
   5 - translocated deposits (alluvial, chemogenic, glacial materials)

3. Sorted/unsorted materials (rank scale, field SORT)
   1 - glacial and pyroclastic
   2 - proluvial
   3 - alluvial
   4 - bog deposits
   5 - chemogenic maritime deposits

4. Chemical composition (nominal scale, field CHIM)
   1 - salted
   2 - calcerous
   3 - siliceous
   4 - others

Appendix 2

List of the Siberian Landscapes

	Name of landscape
1	Altay intensively dissected low mountains with forests
2	Altay intensively dissected middle mountains with alpine meadow-forest vegetation
3	Altay intensively dissected high mountains with tundra-forest vegetation
4	Chuyskaya steppe high mountain lacustrine-glacial slightly dissected poorly drained plain with steppes
5	Burla-Barnaul plate-shaped medium dissected medium drained elevation with forest-steppes
6	Kulunda platy slightly dissected poorly drained plain with steppes
7	Alei-Charym plate-shaped medium dissected medium drained elevation with steppes
8	Pre-Obian lacustrine-alluvial medium dissected medium drained plain with forests
9	Biysk-Chumysh deeply dissected well drained elevation with forest-steppes
10	Salair-Altay intensively dissected well drained mountain system with forests
11	Kolyvan intensively dissected mountains with forest-steppes
12	Kolyvan-Chergi intensively dissected mountains with forests
13	Yenisey-Khatanga coastal plain with arctic tundras
14	North Taimyr mountain with arctic tundras
15	Upper Bystrinskaya mountain with arctic tundras
16	Kheta-Popigai plain with undershrub-moss tundras
17	North Kotui mountain with tundra
18	North Putorana mountain with tundra
19	Lontokoi mountain with tundras
20	Bol'shaya Kheta plain with shrub tundras
21	Kureya-Pakulikha plain with cedar-larch-spruce northern taiga forests
22	Mundului mountain with northern taiga spruce-larch forests
23	Tunguska-Fat'yanikha plain with northern taiga larch-cedar-spruce forests
24	Kellog-Sym plain with northern taiga pine forests
25	Elogui plain with northern taiga cedar-spruce and secondary birch forests
26	Bakhta tableland middle taiga spruce-fir forests
27	Turukhansk plain with open and sparse spruce-larch forests
28	Kheta plain with shrub tundras and open larch forests
29	Kotui mountain with tundra
30	Popigai plain with sparse and open larch forests
31	Kotuikan mountain with sparse and open larch forests
32	Nizhnyaya Tunguska mountain with tundra
33	Moiero-Vilyui mountain with sparse and open larch forests
34	Kondermiy tableland middle taiga spruce-fir forests
35	Chunya tableland middle taiga larch forests
36	Turu mountain with open and sparse larch forests
37	Moiero-Essei mountain with open and sparse larch forests
38	Yenisey-Khantai plain with open and sparse spruce-larch forests
39	Engida low mountain with middle taiga spruce-larch forests
40	Chulokan plain with middle taiga larch-pine forests
41	Kochechum mountain with open and sparse larch forests
42	Vivino-Kotui mountain with tundra and northern taiga larch forests
43	Priozernyi-Ayan mountain with tundra
44	Ayan mountain with tundra
45	Ilimpei mountain with northern taiga pine-larch forests
46	Maimecha mountain with tundra
47	Chapa low mountain with middle taiga pine-larch forests

48	Isakovo low mountain with middle taiga spruce-fir forests
49	Kass plain with middle taiga cedar forests
50	Kas plain with cedar and secondary hardwood forests
51	Sochur plain with pine forests
52	Ket' plain with dark coniferous and secondary birch-aspen forests
53	Tis low mountain with spruce-fir forests
54	Teya mountain with fir-larch and secondary birch forest
55	Vel'mo mountain with larch-spruce forests
56	Uderei plain with pine-larch forests
57	Chadoba tableland pine-larch forests
58	Katanga tableland pine forests
59	Usol'ye low mountain with spruce-fir and secondary birch forest
60	Kemchug plain with spruce-fir and secondary hardwood forests
61	Chulym plain with secondary dark coniferous-hardwood forests
62	Lower Kansk plain with spruce-fir and secondary hardwood forests
63	Aban plain with secondary light coniferous-hardwood forests
64	Upper Chulym low mountain with larch-birch forests
65	Kansk plain with secondary light coniferous-hardwood forests
66	Upper Iyus mountain with dark coniferous-larch forests
67	Tuim low mountain with secondary birch-larch forests
68	Sor mountain with dark coniferous-larch and secondary hardwood forests
69	Tuba plain with secondary light coniferous-hardwood forests
70	Kazyr mountain with fir-cedar forests
71	Mana low-uplands dark-coniferouis and decidouis
72	Agul low-uplands dark-coniferouis and decidouis
73	Komay low-uplands dark-coniferouis and decidouis
74	Abakan plain steppe, sparse larch-birch forest
75	Usinsk mountain with larch-cedar forests
76	Middle Sikhote-Alin' middle mountains with dark coniferous and larch forests
77	Tatarskiy strait-coastal low mountains with broad-leaved hardwood-coniferous-birch forests
78	Khasan-Khankai low mountain with broad-leaved hardwood forests
79	Ussuri-Pre-Khankai meadow-broad-leaved hardwood forests plain
80	Central part of the Middle Sikhote-Alin' low mountains with cedar-broad-leaved hardwood forests
81	Southeastern coastal low mountains with broad-leaved hardwood forests
82	South Sikhote-Alin' middle mountains with coniferous-broad-leaved hardwood and dark coniferous forests
83	Pre-Khankai flat plain with meadow-stepped vegetation
84	Pre-Khankai high hilly plain with forest-steppe
85	Pre-Khankai low mountains with broad-leaved hardwood forests
86	Dzhugdzhur middle mountains with larch forests and mountain forest-tundras
87	Okhotsk-Kav coastal plain with open forest-bog vegetation
88	Yudom-Kulino highlands with unvegetated mountains and open forests
89	Amur-Liman hilly-ridge plain with spruce-larch forests
90	Udyl'-Kizino plain
91	Lower Amgun' middle mountains with spruce-larch forests
92	Bureya-Selemdzha highlands with spruce-larch forests and mountain open forests
93	Evoron-Tugur flat plain with bogs open forests
94	Maya-Uda low mountains with spruce-larch forests

95	Okhotsk coastal low mountains with spruce-larch forests
96	Uchur-Maya low mountains with larch and bog open forests
97	Uda flat plain with larch forests and bogs
98	Dzhugdzhur middle-high mountains with tundras and larch open forests
99	Tatarskiy strait-coastal low mountains with dark coniferous forests
100	North Sikhote-Alin' middle mountains with dark coniferous and larch forests
101	North Sikhote-Alin' low mountains with dark coniferous and coniferous-broad-leaved hardwood forests
102	Middle Amur hilly plain with coniferous-broad-leaved hardwood forests
103	Kur-Urmiy low mountains with cedar-broad-leaved hardwood and dark coniferous forest-tundras and tundras
104	Middle Amur flat plain with coniferous-broad-leaved hardwood forests and bogs
105	Middle Amur hilly ridge piedmont with cedar-broad-leaved hardwood forests
106	Middle Sikhote-Alin' low mountains with cedar-broad-leaved hardwood forests
107	Middle Sikhote-Alin' middle mountains with dark coniferous forests
108	Birobidzhan meadow-bog plain with broad-leaved hardwood forests
109	Pompeevo-Sutar low mountains with cedar-broad-leaved hardwood forests
110	Maly Khingan middle mountains with dark coniferous forests
111	Upper Selemdzha highlands with larch forests
112	Selemdzha hilly plain with birch-larch forests
113	Soktakhan-Dzhagdyn low mountains with birch-larch forests
114	Zeya plain with birch-larch forests
115	Dzhugdyr-Stanovoi highlands with larch forest-tundra and unvegetated mountains
116	Tukuringri-Stanovoi middle mountains with pine-larch forests
117	Arkhar-Bureya low mountains with spruce-larch-birch forests
118	Selemdzha-Tom' bogged plain with larch-birch forests
119	Amur-Zeya hilly plain with pine-birch and oak forests
120	Urkan low mountains with birch-larch forests
121	Zeya-Bureya flat meadow-bog stepped plain
122	Zeya-Bureya hilly plain with forest-steppe
123	Panangan tableland with larch forests
124	Nep plain with larch-pine forests
125	Lower Chan plain with pine-larch forests
126	Gazhen plain with pine forests
127	Lower Chuya mountain with pine-larch forests
128	Vitim mountain with larch forests and mountain tundras
129	Upper Muran plain with pine and secondary hardwood forests
130	Educha tableland pine and secondary hardwood forests
131	Lena plain with pine forests
132	Kirenga mountain with pine forests
133	Lower Biryusa plain with pine and secondary hardwood forests
134	Upper Lena tableland cedar forests
135	Upper Kirenga mountain with larch forests
136	Baikal mountain with spruce-fir and underbald mountains sparse forests
137	Angara-Uda plain with pine and secondary hardwood forests
138	Bratsk plain with pine and secondary hardwood forests
139	Upper Im upland cedar forests
140	Irkusk-Cheremkov plain with forest-steppe secondary light coniferous-hardwood forests
141	Biryusa plain with pine and secondary hardwood forests

142	Uda plain with pine and secondary birch forests
143	Tyagul' mountain with dark coniferous forests
144	Upper Uda mountain with cedar-larch and underbald mountains sparse forests
145	Prebaikalian mountains with pine forests
146	Primorsky mountains with light and dark coniferous forests and underbald mountains sparse forests
147	North Kamchatka provisional landscape of the Sredinny ridge eastern macroslope with crook-stem-creeping vegetation
148	Northeastern coastal lowland provisional landscape with tundra-creeping vegetation
149	Northeastern coastal plain-mountain provisional landscape with crook-stem-creeping vegetation
150	Neck-lowland provisional landscape of coastal river valleys with tundra-bog
151	Koryakskoye high plateau provisional landscape with tundra-unvegetated mountain-creeping vegetation
152	North Okhotsk mountain provisional landscape with tundra-creeping vegetation-open forests
153	Western coastal lowland-plain provisional landscape with tundra-bog vegetation
154	Middle mountain provisional landscape of the Sredinny ridge western macroslope with crook-stem vegetation
155	Mountain provisional landscape of the Sredinny ridge western macroslope with crook-stem-unvegetated mountain-creeping vegetation
156	Central provisional landscape of the Sredinny ridge eastern macroslope with unvegetated mountain-creeping-crook-stem vegetation
157	Coastal lowland-hilly provisional landscape with crook-stem-tundra vegetation
158	Graben-syncline lowland-valley provisional landscape with meadow-forest vegetation
159	Northern provisional landscape of the Sredinny ridge eastern macroslope with unvegetated mountain-creeping-crook-stem
160	Central-Kamchatka landscape of the Sredinny ridge eastern macroslope with creeping-crook-stem provisional vegetation
161	Piedmont-valley provisional landscape of the Central Kamchatka depression with meadow-forest vegetation
162	Piedmont-mountain volcanogenic provisional landscape of the Vostochnyi ridge western macroslope with forests
163	Southwestern lowland-coastal provisional landscape with tundra-bog vegetation
164	Mountain provisional landscape of the Sredinny ridge south with creeping-meadow-crook-stem vegetation
165	Southeastern mountain-coastal provisional landscape with crook-stem-creeping vegetation
166	Eastern-coastal provisional landscape with crook-stem-tundra-bog vegetation
167	South Kamchatka piedmont-plain provisional landscape with forest-meadow vegetation
168	Tom'-Archekas deeply dissected well drained elevation with forest (forest-steppe) vegetation
169	Klya-Tyazhi' eolian well dissected normally drained plain with forest-steppe
170	Salair ridge intensively dissected well drained mountain system with forests
171	Kuznetsk deeply dissected well drained depression with forest-steppe
172	Subarctic-arctic mountain-valley provisional landscape with forest-tundra vegetation
173	Subarctic-arctic lowland-coastal provisional landscape with tundra-bog vegetation
174	Subarctic-arctic-Pacific provisional landscape with tundra-bog vegetation
175	Subarctic lowland provisional landscape of intermontane depression with tundra-meadow vegetation
176	Bering Sea mountain-valley provisional landscape with forest-tundra vegetation

177	Subboreal-boreal provisional landscape with mountain open taiga-creeping vegetation-unvegetated mountains
178	Siberian-boreal mountain-valley provisional landscape with larch-creeping vegetation
179	Subarctic middle- and low mountain provisional landscape with larch-unvegetated mountain-creeping
180	Lower Kolyma subarctic low mountain-valley provisional landscape with open taiga vegetation
181	Subarctic lowland provisional landscape of intermontane depressions with tundra-bog vegetation
182	Boreal-subarctic lowland-bogged provisional landscape of river valleys lower parts
183	North Koryakskoye high plateau provisional landscape with open taiga-creeping-unvegetated mountain vegetation
184	North Okhotsk lowland-coastal provisional landscape with tundra-creeping vegetation
185	Coastal mountain-valley provisional landscape with tundra-creeping vegetation
186	North Okhotsk mountain-coastal provisional landscape with creeping-open forest
187	Vasyugan platy slightly dissected poorly drained plain with forest-bog vegetation
188	Tar-Omsk lacustrine-periglacial medium dissected medium drained plain with forest-bog vegetation
189	Tartas-Omsk lacustrine-periglacial medium dissected medium drained plain with forest-steppe vegetation
190	Tartas-Karasuk' platy slightly dissected poorly drained plain with steppes
191	Chan lacustrine-periglacial slightly dissected poorly drained plain with forest-steppe vegetation
192	Bagan-Kargat lacustrine-periglacial slightly dissected poorly drained plain with forest-steppes
193	Karasuk-Chaus eolian medium dissected medium drained plain with forest-steppes
194	Pre-Obian lacustrine-alluvial well dissected normally drained plain with forest vegetation
195	Suzun-Sokur deeply dissected well drained elevation with forest-steppe vegetation
196	Irtysh-Tui lacustrine-periglacial deeply dissected well drained plain with forest vegetation
197	Ishim-Tar lacustrine-alluvial medium dissected medium drained plain with meadow-bog-forest vegetation
198	Salashi-Omsk lacustrine-platy slightly dissected poorly drained plain with forest-steppes
199	Pre-Irtyshian lacustrine-alluvial slightly dissected poorly drained plain with meadow- forest-steppe vegetation
200	Irtysh-Omsk lacustrine-platy slightly dissected poorly drained plain with forest-steppes
201	Isil'kul'-Irtysh platy slightly dissected poorly drained plain with steppes
202	Middle Sakhalin central hilly plain with larch forests-creeping vegetation
203	North Sakhalin flat coastal plain with larch forests-creeping vegetation
204	North Sakhalin low mountains with spruce-larch forests
205	West Kamyshevo low mountains with dark coniferous forests
206	West Kamyshevo middle mountains with dark coniferous and stone birch forests
207	Poronai flat plain with larch forests
208	East Sakhalin highlands with dark coniferous forests
209	Sakhalin South Kamyshevo low mountains with stone birch-spruce-fir forest
210	South Sakhalin low mountain-plain Cape with dark coniferous and stone birch forests
211	Ob-Yugan lacustrine-periglacial well dissected well drained plain with forests
212	Middle Ob slightly dissected poorly drained floodplain with bog-meadow vegetation
213	Ob-Tym lacustrine-alluvial medium dissected medium drained plain with forests-bog vegetation
214	Vakh-Tym glacial medium dissected medium drained plain with bog-forest vegetation
215	Tym-Paidugino lacustrine-periglacial well dissected normally drained plain with forests
216	Yugan-Vasyugan lacustrine-periglacial medium dissected medium drained plain with forest-bog vegetation

177	Subboreal-boreal provisional landscape with mountain open taiga-creeping vegetation-unvegetated mountains
178	Siberian-boreal mountain-valley provisional landscape with larch-creeping vegetation
179	Subarctic middle- and low mountain provisional landscape with larch-unvegetated mountain-creeping
180	Lower Kolyma subarctic low mountain-valley provisional landscape with open taiga vegetation
181	Subarctic lowland provisional landscape of intermontane depressions with tundra-bog vegetation
182	Boreal-subarctic lowland-bogged provisional landscape of river valleys lower parts
183	North Koryakskoye high plateau provisional landscape with open taiga-creeping-unvegetated mountain vegetation
184	North Okhotsk lowland-coastal provisional landscape with tundra-creeping vegetation
185	Coastal mountain-valley provisional landscape with tundra-creeping vegetation
186	North Okhotsk mountain-coastal provisional landscape with creeping-open forest
187	Vasyugan platy slightly dissected poorly drained plain with forest-bog vegetation
188	Tar-Omsk lacustrine-periglacial medium dissected medium drained plain with forest-bog vegetation
189	Tartas-Omsk lacustrine-periglacial medium dissected medium drained plain with forest-steppe vegetation
190	Tartas-Karasuk' platy slightly dissected poorly drained plain with steppes
191	Chan lacustrine-periglacial slightly dissected poorly drained plain with forest-steppe vegetation
192	Bagan-Kargat lacustrine-periglacial slightly dissected poorly drained plain with forest-steppes
193	Karasuk-Chaus eolian medium dissected medium drained plain with forest-steppes
194	Pre-Obian lacustrine-alluvial well dissected normally drained plain with forest vegetation
195	Suzun-Sokur deeply dissected well drained elevation with forest-steppe vegetation
196	Irtysh-Tui lacustrine-periglacial deeply dissected well drained plain with forest vegetation
197	Ishim-Tar lacustrine-alluvial medium dissected medium drained plain with meadow-bog-forest vegetation
198	Salashi-Omsk lacustrine-platy slightly dissected poorly drained plain with forest-steppes
199	Pre-Irtyshian lacustrine-alluvial slightly dissected poorly drained plain with meadow- forest-steppe vegetation
200	Irtysh-Omsk lacustrine-platy slightly dissected poorly drained plain with forest-steppes
201	Isil'kul'-Irtysh platy slightly dissected poorly drained plain with steppes
202	Middle Sakhalin central hilly plain with larch forests-creeping vegetation
203	North Sakhalin flat coastal plain with larch forests-creeping vegetation
204	North Sakhalin low mountains with spruce-larch forests
205	West Kamyshevo low mountains with dark coniferous forests
206	West Kamyshevo middle mountains with dark coniferous and stone birch forests
207	Poronai flat plain with larch forests
208	East Sakhalin highlands with dark coniferous forests
209	Sakhalin South Kamyshevo low mountains with stone birch-spruce-fir forest
210	South Sakhalin low mountain-plain Cape with dark coniferous and stone birch forests
211	Ob-Yugan lacustrine-periglacial well dissected well drained plain with forests
212	Middle Ob slightly dissected poorly drained floodplain with bog-meadow vegetation
213	Ob-Tym lacustrine-alluvial medium dissected medium drained plain with forests-bog vegetation
214	Vakh-Tym glacial medium dissected medium drained plain with bog-forest vegetation
215	Tym-Paidugino lacustrine-periglacial well dissected normally drained plain with forests
216	Yugan-Vasyugan lacustrine-periglacial medium dissected medium drained plain with forest-bog vegetation

217	Vasyugan-Ob lacustrine-alluvial medium dissected medium drained plain with bog-forest vegetation
218	Southern Ob slightly dissected poorly drained floodplain with bog-meadow vegetation
219	Ob-Ket' lacustrine-alluvial medium dissected medium drained plain with forest-bog vegetation
220	Paidugino-Ket' lacustrine-periglacial medium dissected medium drained plain with bog-forest vegetation
221	Ket'-Tym lacustrine-periglacial deeply dissected well drained plain with bog-forest vegetation
222	Vasyugan-Iksa lacustrine-periglacial well dissected well drained plain with forest vegetation
223	Iksa-Ob lacustrine-periglacial well dissected well drained plain with agricultural-forest vegetation
224	Ket'-Chulym lacustrine-periglacial well dissected well drained plain with forests
225	Chulym lacustrine-periglacial deeply dissected well drained plain with agricultural-forest vegetation
226	Northern Yamal plain with tundra
227	Eastern strongly dissected well drained mountain macroslope of the Polar Urals with forest-tundra
228	Polar-Transuralian glacial deeply dissected well drained elevation with forest-tundra
229	Nadym-Ob glacial medium dissected medium drained plain with forest-tundra
230	Nadym-Pur lacustrine-alluvial slightly dissected poorly drained plain with forest-tundra
231	Nadym-Pur glacial medium dissected medium drained plain with forest-tundra
232	Middle Pur lacustrine-alluvial slightly dissected poorly drained plain with forest-tundra
233	Middle Pur-Taz glacial medium dissected medium drained plain with forest-tundra
234	Middle Taz lacustrine-alluvial slightly dissected medium drained plain with forest-tundra
235	Kheyakha-Sidorovskiy glacial medium dissected medium drained plain with forest-tundra
236	Eastern strongly dissected well drained mountain macroslope of the Northern Urals with forest-tundra
237	Sos'va-Volinskaya glacial deeply dissected well drained elevation with forests
238	Sos'va lacustrine-alluvial medium dissected medium drained plain with forest-bog vegetation
239	Sos'va-Syn glacial deeply dissected well drained elevation with forests
240	Lyulinvor glacial deeply dissected well drained elevation with forests
241	Lower Ob slightly dissected poorly drained plain with bog-meadow vegetation
242	Kunovat-Polui lacustrine-alluvial slightly dissected poorly drained plain with forest-bog-tundra vegetation
243	Polui glacial medium dissected medium drained plain with forest-bog-tundra vegetation
244	Nadym-Pur-Taz glacial slightly dissected poorly drained plain with forest-bog-tundra vegetation
245	Khudosey-Taz glacial medium dissected medium drained plain with forest-bog-tundra vegetation
246	Siberian Ouvals glacial deeply dissected well drained elevation with forest-bog vegetation
247	Upper Taz glacial deeply dissected well drained elevation with forests
248	Tol'ka-Taz lacustrine-alluvial slightly dissected poorly drained plain with forest-bog vegetation
249	Topsui-Mal-Sos'va glacial deeply dissected well drained plain with forests
250	Serginskiy-Seul' lacustrine-alluvial medium dissected medium drained plain with forest-bog vegetation
251	Belogorkiy materik glacial deeply dissected well drained elevation with forests
252	Nazym-Loshin lacustrine-alluvial medium dissected medium drained plain with bog-forest vegetation
253	Surgutskoe poles'ye lacustrine slightly dissected poorly drained plain with forest-bog vegetation
254	Agan ridgy glacial well dissected normally drained plain with forest vegetation
255	Vakh lacustrine slightly dissected poorly drained plain with forest-bog
256	Upper Tazov glacial deeply dissected well drained plain with forest
257	Konda-Kush lacustrine-alluvial slightly dissected well drained plain with forest-bog vegetation

258	Konda lacustrine-alluvial slightly dissected poorly drained plain with forest-bog vegetation
259	Ob-Irtysh lacustrine-alluvial medium dissected medium drained plain with bog-forest vegetation
260	Ob-Yugan lacustrine-periglacial well dissected normally drained plain with forests
261	Pim-Vakh Pre-Obian lacustrine-alluvial medium dissected medium drained plain with forest-bog vegetation
262	Vakh-Tym glacial medium dissected medium drained plain with forest-bog vegetation
263	Salym-Yugan lacustrine slightly dissected poorly drained plain with forest-bog vegetation
264	Yugan lacustrine medium dissected medium drained plain with bog-forest vegetation
265	Tyrgun-Tan lacustrine-alluvial medium dissected medium drained plain with forest-bog vegetation
266	Kazym lacustrine-alluvial slightly dissected poorly drained plain with forest-bog vegetation
267	Ob-Amnyan glacial well dissected normally drained plain with forests
268	Kuma-Tavda lacustrine-alluvial medium dissected medium drained plain with bog-forest vegetation
269	Tobol-Konda lacustrine-alluvial poorly dissected poorly drained plain with forest-bog vegetation
270	Tobolskiy materik lacustrine-periglacial medium dissected medium drained plain with bog-forest vegetation
271	Turtas-Dem'yanovsk lacustrine-periglacial medium dissected medium drained plain with forest-bog vegetation
272	Tobol-Tavda lacustrine-periglacial medium dissected medium drained plain with meadow-bog-forest vegetation
273	Tobol-Ishim lacustrine-platy slightly dissected poorly drained plain with forest-steppe
274	Ishim platy slightly dissected poorly drained plain with steppe vegetation
275	Muiya-Kuanda depression with bogged larch forests
276	Upper Kalar mountain with larch forests mountain tundra
277	Upper Chara depression with bogged larch forests
278	Shilka-Vitim mountain with larch forests
279	Ingoda plain with steppe light coniferous-hardwood forests
280	Shilka mountain with secondary light coniferous-hardwood forests
281	Borzya mountain with forest-steppe secondary larch-birch forests
282	Kulusutay plateau salted steppe
283	Upper Angara plain with bogged pine-larch forests
284	Muiya mountain with larch forests mountain tundra
285	Muiya-Kuanda depression with bogged pine-larch forests
286	Barguzin plain with bogged pine-larch forests
287	Upper Vitim mountain with larch forests
288	Uda mountain with pine forests
289	Selenga Mouth bogged plain
290	Upper Oka mountain with cedar-larch forests and mountain tundras
291	Upper Irkutsk plain with pine-larch and secondary birch forests
292	Snezhninsk plain with cedar-larch and secondary birch forests
293	Temnik mountain with larch-dark coniferous forests
294	Selenga plain with forest-steppe secondary pine-birch forests
295	Upper Khilon mountain with pine-cedar forests
297	Upper Tapsa mountain with larch-cedar forests and mountain tundra
299	Upper Elegest mountain with larch-cedar forests and mountain tundra
300	Tes-Khem plain with scattered clumps of steppe larch forests
301	Upper Yenisey mountain with cedar-larch forests
302	Bediy-Belik mountain with cedar forests and mountain tundra
303	Upper-Abakan mountain fir-cedar forests

304	Kyzyl mountain with stepped larch forests
305	Olenek-Anabar arctic tundra lowlands
306	Yana-Kolyma arctic tundra valley
307	Kolyma-Yukogir tableland with larch forest-tundras
308	Alazeiko tableland with larch forest-tundra
309	Kolyma-Indigirka bog-lacustrine plain with open larch forests
310	Cherskiy-Mom high mountains with larch-creeping stone pine forest-tundras
311	Upper Indigirka low-middle mountains with open larch forests and creeping stone pine forest
312	Yana tableland with open larch forests
313	Upper Yana uplands with forest-tundra and creeping stone pine vegetation
314	Lower Lena high plain with open larch forests
315	River Lena delta with arctic tundras
316	Olenek-Anabar tableland with forestwith bogs and open forests
317	Anabar mountain with tundra
318	North Verkhoyansk arctic desert uplands
319	Yana-Indigirka arctic tundra tableland with forest-tundra
320	Vilyui-Lena low plateau with pine-larch forests
321	Central Yakutiya flat bogged plain with larch-pine forests
322	Markha-Vilyui low plateau with larch forests and bogs
323	South Verkhoyansk piedmont with pine-larch forests
324	Verkhoyansk uplands mountains with open larch-creeping stone pine vegetation
325	Amgulen flat bog plain with pine-larch open and closed forests
326	Pre-Lena low plateau with pine-larch forests and bogs
327	Vilyui-Lena high plateau with pine-larch forests
328	Amga-Lena low mountains with pine-larch forests
329	Olekma-Aldan uplands with spruce-larch forests and creeping stone pine vegetation
330	Vilyui plateau with larch forests
331	Aldan-Ugur uplands with larch open and closed forests
332	Aldan-Daban low plateau with pine-larch forests
333	Setedaban high mountains with open larch forests and unvegetated mountains
334	Tobol-Irtysh lacustrine-periglacial medium dissected medium drained plain with meadow-bog-forest vegetation
340	Northern Nadym-Ob glacial medium dissected medium drained plain with tundra
341	Northern Nadym-Pur lacustrine-alluvial slightly dissected poorly drained plain with tundra
342	Northern Nadym-Pur glacial medium dissected medium drained plain with tundra
343	Northern Middle Pur lacustrine-alluvial slightly dissected poorly drained plain with tundra
344	Northern Middle Pur-Taz glacial medium dissected medium drained plain with tundra
345	Northern Middle Taz lacustrine-alluvial slightly dissected medium drained plain with tundra
346	Northern Kheyakha-Sidorovskiy glacial medium dissected medium drained plain with tundra
347	Northern Eastern strongly dissected well drained mountain macroslope of the Polar Urals with tundra