Analysis of relationships between topography, ring structures, soil cover and rocks

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ABSTRACT
We carried out an analysis of relationships between topography, ring structures, soil cover and rocks at a regional scale. The study area was the Ural Region, Russia. We (a) compiled a map of convergence and divergence areas, (b) produced a map of ring structures, and (c) carried out a combined analysis of these two maps and a set of soil and geological data. The following regularities were found. Let there be two ring structures defined by two circles. These circles border two heterogeneous subsets M and N of convergence and divergence areas. Let one circle intersects another. This brings into existence a segment including a subset L of convergence and divergence areas. A design of the subset L differs from designs of the subsets $(N–L)$ and $(M–L)$. Segmentation of the subset M can be observed until a subset K can be separated. This subset has a homogeneous design of convergence and divergence areas. Different groups of subsets K can be merged into extended 'clusters' with dominant soil complexes and rocks. Terrain fragmentation into segments and their merging into 'clusters' can be considered as a formalised protocol for determination of borders of areas marked by dominant soil complexes and rocks.

INTRODUCTION

The term 'ring structure' is common for description of lithospheric structures of various origins (e.g., plutonic, magmatic, volcanic, impact) and sizes (from several meters to several hundreds of kilometers across) which are manifested on the landsurface as radial-concentric distribution of the following landscape features:

- Topographic elements, such as valleys, ridges, chains of depressions;
- Drainage network, such as rivers, chains of lakes and swamps;
- Elements of geological structure, such as faults, folds, rocks of like age or origin;
- Mosaic of soil cover;
- Mosaic of plant cover; and
- Anomalies of geophysical fields.

Extensive geological studies are devoted to the problem of ring structures (Solovyev, 1978; Trifonov et al., 1983; Boosh, 1986). Summary maps of ring structures were compiled for great areas (Solovyev, 1977; Shcheglov, 1979; Kozlovsky, 1984). Data on ring structures were used to solve some urgent problems, for example, in tectonic modelling (Zejlik, 1978; Yezhov and Khudyakov, 1984) and in mineral prospecting (Tomson et al., 1984).

Ring structures are natural geological objects manifested as ordered distribution of other elements of the landscape. Therefore, it would appear reasonable that there are some interrelationships between ring structures and non-geological elements of the landscape. For example, a ring structure is manifested as a set of radial-concentric faults, which can serve as pathways for upward transport of deep-seated substances and groundwater to the landsurface. In this case, some soil properties, such as microelement and moisture contents, can be controlled by the ring

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structure. Unfortunately, relationships between soil cover properties and ring structures are poorly known. Thus, Stepanov (1986) demonstrated that a mosaic of the soil cover is controlled by topographically expressed ring structures: it also has a radial-concentric design. It is obvious that more sophisticated analysis of these relationships can be of fundamental importance in geosciences.

This investigation was connected with a development of a small-scale map of landsurface systems and soil cover of the Ural Region (Kuryakova et al., 1991) and a study of a soil cover structure of this territory (Fedichkina, 1993). The aim of this work was to determine and analyse regularities of interrelationships between relief, ring structures, soil cover and rocks at a regional scale.

STUDY AREA

The study area is a part of the Ural Region and adjacent territories of Russian Federation and northern Kazakhstan between 50° and 62° N, and 50° and 69° E. The area measures approximately 1200 km by 1100 km. It is marked by a diversity of relief, geological structure and soil cover. The study area is complicated by many faults (Nalivkin, 1970, 1980; Rozanov, 1970) and ring structures (Solovyev, 1977; Shcheglov, 1979; Kozlovsky, 1984).

The Southern, Central, and Northern Ural Mountains occupy the central part of the study area. The Northern Urals stretch in the north direction and consist of several parallel ridges with flat summits (1000–1200 m) divided by lateral depressions. The Central Urals is the lowest part of the Ural Mountains (up to 994 m). The Southern Urals consist of many ridges (up to 1640 m) stretching in the north and the southwest directions and divided by crosscut and lateral deep depressions and valleys. The Urals are epiplatformian middle mountains corresponding to the Ural Hercynian folding zone. The Ural foredeep is marked by relatively shallow bedding of sedimentary Palaeozoic strata. There are early and middle Palaeozoic limestones, dolomites and sandstones highly contorted and deformed by thrusts in the western slope of the Urals. The Central Ural anticlinorium comprises Palaeozoic and Precambrian sedimentary strata and some crystalline rocks of older ages. The Magnitogorsk, the Tagil and the Eastern Ural synclinoria are generally formed by middle Palaeozoic volcanic strata and marine sediments breached by gabbroids, granitoids and acid intrusions. Yields of older metamorphic rocks and granitoids are abundant in the Ural-Tobol anticlinorium (Rozanov, 1970; Nalivkin, 1980).

The eastern edge of the East European plain (elevations are up to 400 m) is located west of the Urals. There are moraine, outwash, lacustrine-glacial, and alluvial plains as well as moraine-erosion ridges in the north. There are erosion-denudation uplands and accumulative depressions in the south. The plain corresponds to the East European Precambrian platform including an eastern part of the Volga-Ural anteclise and a northeastern part of the Caspian syneclise. The basement of the platform is formed by highly dislocated crystalline rocks of Precambrian age. Generally, the sedimentary cover comprises early and late Permian clastic rocks and dolomites. Early Triassic dolomites and gypsums as well as early Cretaceous, middle and late Jurassic dark clays and glauconite sands are frequently occur in the north-west (Rozanov, 1970; Nalivkin, 1980).

The western edge of the West Siberian plain (elevations are up to 300 m) is located east of the Urals. This is inclined plain including wide flat interstream waterlogged areas. There are flat basins of old lake there, moraine ridges in the north, and low sand ridges in the south. The West Siberian plain has developed within the West Siberian Epihercynian plate. Highly dislocated Palaeozoic deposits form its basement covered by marine and terrestrial loose clays, sandstones and marls (Rozanov, 1970; Nalivkin, 1980).

There is the geographical zonality of the soil distribution in the plains. Gleyzems (*Gleysols*) are dominant in the northern taiga, Podzolic soils (*Dystric Albeluvisols*) – in the middle taiga, Sod-podzolic soils (*Eutric Albeluvisols*) – in the southern taiga; Grey Forest soils (*Greyzems*) – in the hardwood forest, Podzolized, Leached and Typical Chernozems (*Luvic Phaeozems, Luvic* and *Chernic Chernozems*) – in the forest-steppe, Ordinary and Southern Chernozems (*Haplic* and *Calcic Chernozems*) – in the steppe, and Chestnut soils (*Kastanozems*) are typical in the dry steppe. Vertical soil zonality is observed in the Urals. Mountain grey Forest and Mountain-meadow Sod soils (*Eutric* and *Umbric Leptosols*) are dominant in the Southern Urals. Brownzems, Mountain Podzolic and Sod-podzolic soils (*Dystric Cambisols, Dystric* and *Mollic Leptosols*) are typical in the Northern and Central Urals (Kaurichev and Grechin, 1969). In the paper we use Russian names of soils (Yegorov et al., 1977) with their FAO equivalents given in italic (Stolbovoi, 1998; FAO, 1998).

MATERIALS AND METHODS

As initial data, we used the following small-scale maps:

- Map of the horizontal curvature of the Ural Region (Stepanov et al., 1988);
- Soil map of the Non-Chernozemic zone of Russia (Fridland, 1978);
- Soil map of Russia (Fridland, 1988);
- Soil map of Kazakhstan (Prasolov and Gerasimov, 1946);
- Geological map of the Russian platform (Nalivkin, 1970);
- Geological map of the USSR (Nalivkin, 1980).

Horizontal curvature (k_h) is the curvature of a normal section of the landsurface; this section is perpendicular to the normal section including the gravity acceleration vector at a given point on the landsurface (Shary, 1991). k_h is a measure of convergence of overland and intrasoil flows: flow diverges when $k_h > 0$, and converges when $k_h < 0$ (Kirkby and Chorley, 1967; Shary, 1991). From geomorphic point of view, divergence areas relate to ridges while convergence areas correspond to valleys (Evans, 1980; Shary, 1991, 1995). k_h is derived from digital elevation models (DEMs) by different algorithms (Evans, 1980; Zevenbergen and Thorne, 1987; Florinsky, 1998b). Among other digital terrain models, data on k_h are commonly used in soil science, geology, geomorphology, and interdisciplinary fields (Moore et al., 1991; Shary et al., 1991; Florinsky, 1998a), in particular to recognise lineaments, ring structures and faults (Florinsky, 1992, 1996, 1998b, 2000).

The map of the horizontal curvature of the Ural Region, scale 1:1,500,000 (Stepanov et al., 1988) was compiled using seventy-two maps of k_h, scale 1:300,000 for the study area. These middle-

scale maps of k_h in turn were derived from topographic maps of the same scale using the method of 'relief plasticity' (Stepanov et al., 1984). This is a version of a grapho-analytical method for k_h map derivation described by Sobolevsky (1932). According to this method, one should determine points of inflection of contours on a topographic map, that is, points marked by zero values of the contour curvature, $\tilde{k}_h = 0$. Then, one should draw isopleths of $\tilde{k}_h = 0$ through these points. Since the geometrical locus of $\tilde{k}_h = 0$ is also the ensemble of points with $k_h = 0$ (Shary, 1991), so isopleths of $\tilde{k}_h = 0$ are borders between areas marked by $k_h > 0$ and $k_h < 0$ – divergence and convergence areas, correspondingly.

The method of 'relief plasticity' is a visual-manual processing of initial topographic data. So, it is characterised by (a) personal errors, (b) ambiguity to draw isopleths of $\tilde{k}_h = 0$ in the neighborhood of irregularities of the topographic surface (e.g., saddle points, horizontal flat areas), and (b) impossibility to draw isopleths of $\tilde{k}_h \neq 0$ and $k_h \neq 0$ (Shary, 1991). Though, to develop soil and some other special maps the method of 'relief plasticity' was repeatedly and successfully used to take into consideration *a priori* known relationships between relief and natural objects and processes under study (Kovda, 1987; Stepanov, 1989). Therefore, it is safe to assume that the map of the horizontal curvature of the Ural Region (Stepanov, 1988) is sufficiently objective material.

We transformed the map of the horizontal curvature of the Ural Region (Stepanov, 1988) into a map of convergence and divergence areas of the same scale: convergence and divergence areas were painted in white and black colours, correspondingly (Fig. 1). This allowed us to present k_h data in more pictorial, readable and convenient form for further analysis.

Then, we carried out a visual analysis of the map of convergence and divergence areas (Fig. 1) to compile a map of ring structures (Fig. 2). We recognised ring structures as follows: First, we found arc-like elements of different sizes in the black-and-white design of convergence and divergence areas (Fig. 1). As a rule, these were arc-like valleys and ridges as well as their fragments spatially distributed as arc-like chains. Second, we closed arcs found to complete circles.

It is obvious, that visual recognition of ring structures is a subjective method and can cause operator's errors. Indeed, ring structures are slightly manifested in the landsurface because of prolonged erosion. In addition, intersection of ring structures of different sizes leads to rather complicated integral pattern. Therefore, ring structures are hard to recognise accurately on scenes and maps. However, human visual system carries out good filtering of a friendly signal from a noise image: an inspector recognises type of figure (with its unknown coordinates) with a probability of 0.41–0.92 (Krasilnikov, 1986).

Finally, we performed a comparative analysis of the map of convergence and divergence areas (Fig. 1), the map of ring structures (Fig. 2), and some small-scale soil and geological maps of the region (Fridland, 1978, 1988; Prasolov and Gerasimov, 1946; Nalivkin, 1970, 1980) to determine regularities in spatial distribution of ring structures, and properties of relief, soil cover and rocks.

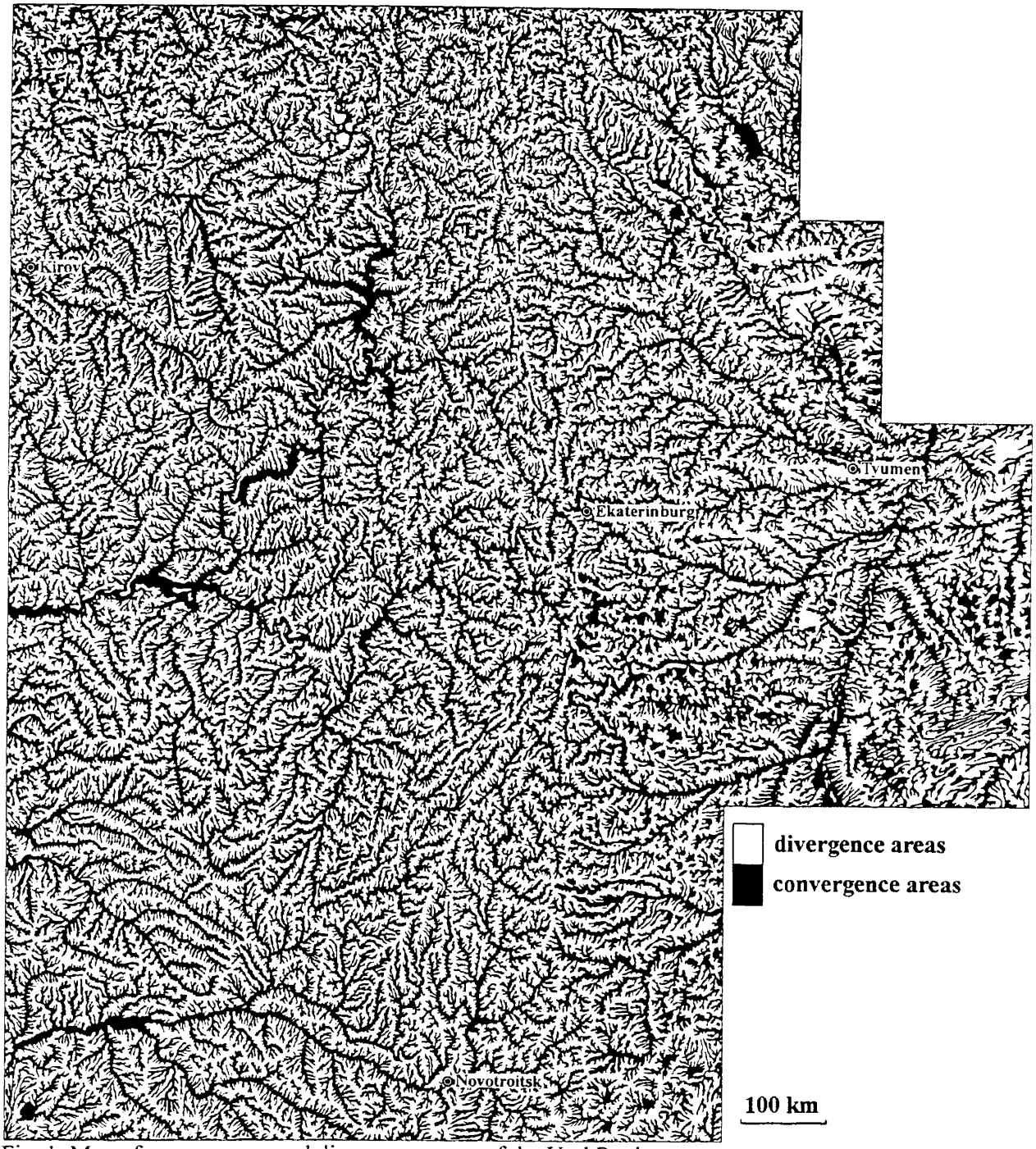


Fig. 1. Map of convergence and divergence areas of the Ural Region.

RESULTS AND DISCUSSION

The map of convergence and divergence areas (Fig. 1) clearly displays a drainage network and a topographic variety of the region. Distinct designs of convergence and divergence areas correspond to different terrains. This is an expected result since distinct types of relief can be marked both by different statistical distribution of values of topographic variables including k_h (Evans, 1980), and by distinct designs of convergence and divergence areas (Stepanov, 1986,

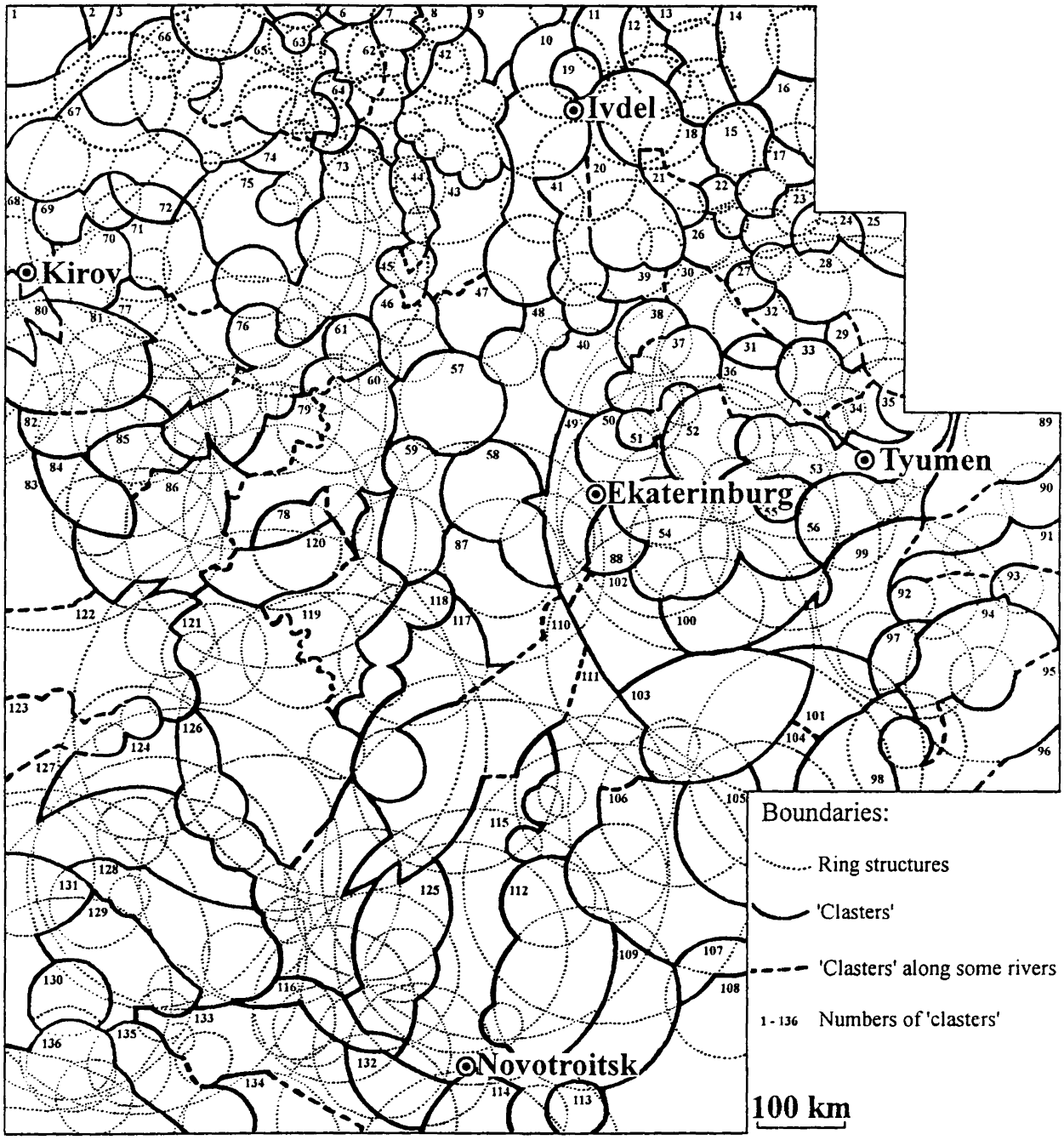


Fig. 2. Map of ring structures and 'clusters' of the Ural Region.

1989).

The combined analysis of the map of convergence and divergence areas (Fig. 1) and the map of ring structures (Fig. 2) allowed us to find the following regularity. Let there be two ring structures defined by two circles with radiuses of R_m and R_n (Fig. 3a). These circles border two subsets M and N of convergence and divergence areas (Fig. 3b, c). The subsets M and N are heterogeneous because they include territories with distinct designs of convergence and divergence areas.

Let the circle with the radius of R_n intersects the circle with radius of R_m. This brings into existence a segment situated within the both ring structures. This segment includes a subset *L* of convergence and divergence areas (Fig. 3d). A design of the subset *L* differs from designs of both the subset (*N–L*) and the subset (*M–L*). A design of the subset (*N–L*) is also differs from a design of the subset (*M–L*). A design of the subset *L* is more homogeneous than designs of the subsets *M* and *N*. It has been found experimentally that fractination of the subset *M* (or *N*) by intersection with other subsets can be observed until a subset *K* can be separated. For a given scale, the subset *K* is marked by a homogeneous design of convergence and divergence areas.

So, using the map of convergence and divergence areas (Fig. 1) and the map of ring structures (Fig. 2) one can separate the study area into small segments marked by homogeneous designs of convergence and divergence areas. In studies of plain and mountainous regions of the Middle Asia, Stepanov (1986, 1989) has found that specific types of relief, soil complexes and rocks correspond to distinct designs of convergence and divergence areas. However, we did not find this regularity for each segment–subset *K* of the Ural Region by the combined analysis of the map of convergence and divergence areas (Fig. 1), the map of ring structures (Fig. 2), soil (Fridland, 1978, 1988; Prasolov and Gerasimov, 1946) and geological (Nalivkin, 1970, 1980) maps. We suppose that this resulted from insufficient resolution of soil and geological data used.

However, we found that different groups of subsets *K* can be merged into rather extended 'clusters' (Fig. 2) with dominant soil complexes and rocks. For example, within the 'cluster' 109 (Fig. 2) there are Southern Chernozems (*Calcic Chernozems*) on crests, Light Chestnut soils (*Haplic Kastanozems*) on slopes, and Meadow soils (*Haplic Gleysols*) and Acid Alluvial soils (*Dystric Fluvisols*) in depressions (Table). At the same time, within the adjacent 'cluster' 112 (Fig. 2) there are Ordinary Chernozems (*Haplic Chernozems*) on crests, Solonetzs (*Haplic Solonetz*) on slopes, and Solonetzic Chernozems (*Luvic Chernozems*) and Meadow Alluvial soils (*Umbric Fluvisols*) in depressions (Table). Early Devonian and early Carboniferous rocks dominate within the 'cluster' 109, while Early Carboniferous and Permian rocks are typical for the 'cluster' 112 (Table).

136 'clusters' were recognised within the Ural Region (Fig. 2 and Table). Although 'clusters' include subsets *K* with different designs of convergence and divergence areas, one can find the most typical designs for each 'cluster'. These typical designs of convergence and divergence areas as well as soil and geological characteristics are presented in Table.

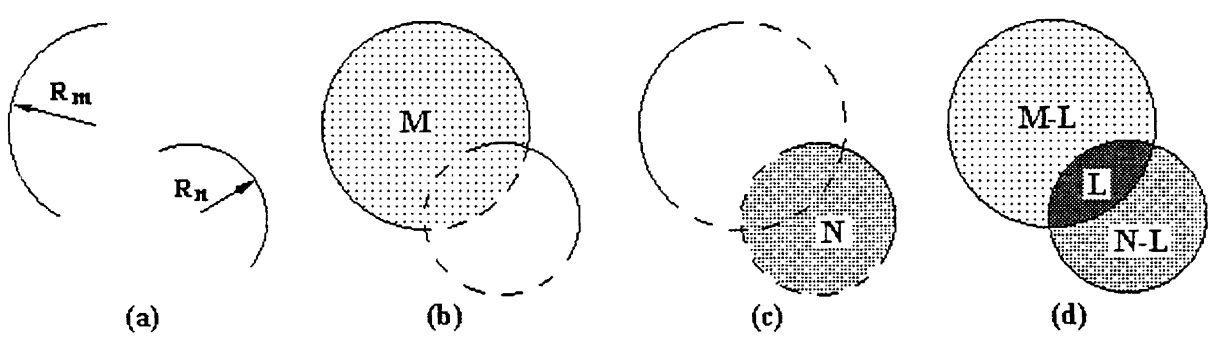
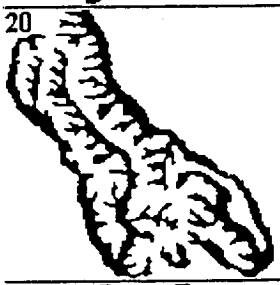
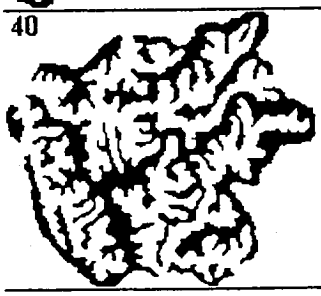
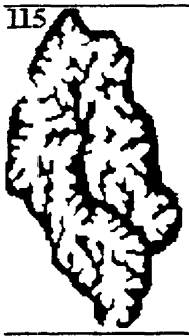
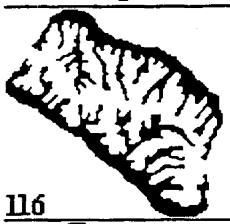
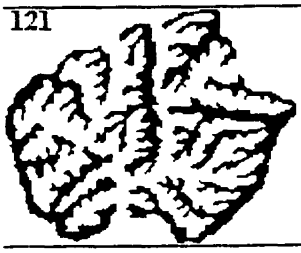


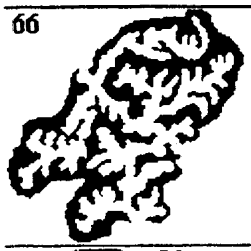
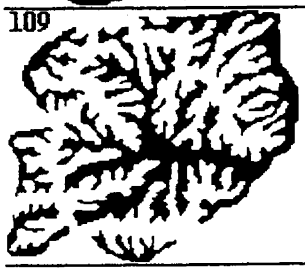
Fig. 3. Segmentation of ring structures (explanations are in the text).

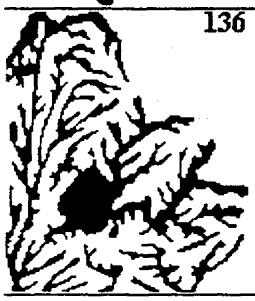
Table. Examples of topographic, soil and geological characteristics of 'clusters' (Fig. 4).

Design of convergence and divergence (black and white) areas	Soils of crests (C), slopes (S), and depressions (D)	Rock age
 8	**C** Podzolics (*Dystric Albeluvisols*) **S** High moor peat soils (*Fibric Histosols*) **D** Acid Alluvials (*Dystric Fluvisols*)	Early Permian Late Permian
 15	**C** Sod-podzolics (*Eutric Albeluvisols*) **S** High moor peat soils (*Fibric Histosols*) Taiga Gleyzems (*Dystric Gleysols*) **D** Acid Alluvials (*Dystric Fluvisols*) Peat Podzolic-gleys (*Gleyi-Histic Albeluvisols*)	Middle Pleistocene
18 	**C** Peaty and peat boggy Gleyzems (*Histic Gleysols*) Taiga Gleyzems (*Dystric Gleysols*) **S** High moor peat soils (*Fibric Histosols*) Peat Podzolic-gleys (*Gleyi-Histic Albeluvisols*) **D** Acid Alluvials (*Dystric Fluvisols*)	Middle Pleistocene Eocene + Oligocene
20 	**C** Podzolics (*Dystric Albeluvisols*) **S** Peat Podzolic-gleys (*Gleyi-Histic Albeluvisols*) High moor peat soils (*Fibric Histosols*) **D** Acid Alluvials (*Dystric Fluvisols*)	Eocene Middle Pleistocene
38 	**C** Peat Podzolic-gleys (*Gleyi-Histic Albeluvisols*) **S** Sod-podzolics (*Eutric Albeluvisols*) High moor peat soils (*Fibric Histosols*) **D** Acid Alluvials (*Dystric Fluvisols*)	Eocene Palaeocene
40 	**C** Peat Podzolic-gleys (*Gleyi-Histic Albeluvisols*) High moor peat soils (*Fibric Histosols*) **S** Mountain Sod-podzolics (*Mollic Leptosols*) Mountain Podzolics (*Dystric Leptosols*) **D** Podzolics (*Dystric Albeluvisols*) Sod-podzolics (*Eutric Albeluvisols*)	Eocene Ordovician

42 	**C** Mountain-meadow Sod soils (*Umbric Leptosols*) Raw-humic Brownzems (*Dystric Cambisols*) **S** Podzolics (*Dystric Albeluvisols*) **D** Acid Alluvials (*Dystric Fluvisols*)	Carboniferous Devonian
49 	**C** Mountain Sod-podzolics (*Mollic Leptosols*) **S** Sod-podzolic-gleys (*Gleyic Albeluvisols*) High moor peat soils (*Fibric Histosols*) **D** Acid Alluvials (*Dystric Fluvisols*) Dark-grey Forest soils (*Haplic Greyzems*)	Ordovician Devonian
 62	**C** Surficialy-gleyed Podzolics (*Stagnic Albeluvisols*) **S** Podzolics (*Dystric Albeluvisols*) High moor peat soils (*Fibric Histosols*) **D** Acid Alluvials (*Dystric Fluvisols*) Transitional moor peat soils (*Dystric Histosols*)	Late Permian Early Permian
 63	**C** High moor peat soils (*Fibric Histosols*) **S** Transitional moor peat soils (*Dystric Histosols*) **D** Boggy Alluvials (*Umbric Fluvisols*)	Holocene
64 	**C** High moor peat soils (*Fibric Histosols*) **S** Transitional moor peat soils (*Dystric Histosols*) **D** Boggy Alluvials (*Umbric Fluvisols*)	Holocene
65 	**C** Podzolics (*Dystric Albeluvisols*) **S** Illuvial-ferruginous Podzols (*Ferric Podzols*) High moor peat soils (*Fibric Histosols*) **D** Acid Alluvials (*Dystric Fluvisols*) Transitional moor peat soils (*Dystric Histosols*)	Late Permian Holocene

112 	**C** Ordinary Chernozems (*Haplic Chernozems*) **S** Solonetzs (*Haplic Solonetz*) Solonetzic Chernozems (*Luvic Chernozems*) **D** Meadow Alluvials (*Umbric Fluvisols*)	Early Carboniferous Permian
113 	**C** Chestnuts (*Haplic Kastanozems*) **S** Solonetzic Chestnuts (*Luvic Kastanozems*) **D** Solonetzs (*Haplic Solonetz*)	Early Carboniferous Middle Carboniferous
115 	**C** Podzolized Chernozems (*Luvic Phaeozems*) Southern Chernozems (*Calcic Chernozems*) **S** Ordinary Chernozems (*Haplic Chernozems*) Solonetzs (*Haplic Solonetz*) **D** Meadow Alluvials (*Umbric Fluvisols*)	Middle + Late Devonian Early Carboniferous
 116	**C** Calcareous Chernozems (*Calcic Chernozems*) **S** Meadow Chernozemics (*Haplic Phaeozems*) Ordinary Chernozems (*Haplic Chernozems*) **D** Meadow Alluvials (*Umbric Fluvisols*)	Late Permian Early Triassic
 119	**C** Dark-grey Forest soils (*Haplic Greyzems*) **S** Grey Forest soils (*Haplic Greyzems*) Meadow Chernozemics (*Haplic Phaeozems*) **D** Acid Alluvials (*Dystric Fluvisols*)	Late Permian Pliocene
120 	**C** Grey Forest soils (*Haplic Greyzems*) **S** Light-grey Forest soils (*Eutric Albeluvisols*) **D** Acid Alluvials (*Dystric Fluvisols*) Low moor peat soils (*Eutric Histosols*)	Late Permian Pleistocene + Holocene
121 	**C** Typical Chernozems (*Chernic Chernozems*) Dark-grey Forest soils (*Haplic Greyzems*) **S** Leached Chernozems (*Luvic Chernozems*) Podzolized Chernozems (*Luvic Phaeozems*) **D** Meadow Alluvials (*Umbric Fluvisols*) Low moor peat soils (*Eutric Histosols*)	Late Permian Pliocene

66 	**C** Peat Podzolic-gleys (*Gleyi-Histic Albeluvisols*) Podzolics (*Dystric Albeluvisols*) **S** Illuvial-ferruginous Podzols (*Ferric Podzols*) High moor peat soils (*Fibric Histosols*) **D** Acid Alluvials (*Dystric Fluvisols*)	Early Triassic Middle Jurassic
92 	**C** Solods (*Eutric Planosols*) **S** Solodic grey Forest soils (*Haplic Greyzems*) Leached Chernozems (*Luvic Chernozems*) **D** Meadow Alluvials (*Umbric Fluvisols*) Low moor peat soils (*Eutric Histosols*)	Neogene
95 	**C** Solonetzic Chernozems (*Luvic Chernozems*) **S** Solonetzs (*Haplic Solonetz*) **D** Low moor peat soils (*Eutric Histosols*)	Pliocene Miocene
97 	**C** Solonetzs (*Haplic Solonetz*) **S** Leached Chernozems (*Luvic Chernozems*) Meadow Chernozemics (*Haplic Phaeozems*) **D** Meadow Alluvials (*Umbric Fluvisols*)	Neogene
99 	**C** Pine forest sands (*Cambic Arenosols*) **S** Solodic grey Forest soils (*Haplic Greyzems*) Solonetzs (*Haplic Solonetz*) **D** Meadow Alluvials (*Umbric Fluvisols*) Low moor peat soils (*Eutric Histosols*)	Oligocene
109 	**C** Southern Chernozems (*Calcic Chernozems*) **S** Light Chestnuts (*Haplic Kastanozems*) **D** Meadow soils (*Umbric Gleysols*) Acid Alluvials (*Dystric Fluvisols*)	Early Devonian Early Carboniferous

122 	**C** Typical Chernozems (*Chernic Chernozems*) Grey Forest soils (*Haplic Greyzems*) **S** Leached Chernozems (*Luvic Chernozems*) Light-grey Forest soils (*Eutric Albeluvisols*) **D** Meadow Alluvials (*Umbric Fluvisols*)	Late Permian Pliocene
136 	**C** Chestnuts (*Haplic Kastanozems*) **S** Solonetzic Chestnuts (*Luvic Kastanozems*) Meadow Chestnut soils (*Haplic Phaeozems*) **D** Solonetzs (*Haplic Solonetz*)	Middle Pleistocene Late Pleistocene

'Clusters' with close soil and geological properties can be marked by close design of convergence and divergence areas. For example, within the 'clusters' 63 and 64 (Fig. 2) there are High moor peat soils (*Fibric Histosols*) on crests, Transitional moor peat soils (*Dystric Histosols*) on slopes, and Boggy Alluvial soils (*Umbric Fluvisols*) in depressions (Table). Both of these 'clusters' are marked by rather close design of convergence and divergence areas, which may be described as variously shaped 'islands' of a sort (Table). Notice that 'clusters' 63 and 64 are 50 km apart, and there is the 'cluster' 65 between them (Fig. 2). The 'cluster' 65 is marked both by other soil complex with dominant Podzolic soils (*Dystric Albeluvisols*), and by other design of convergence and divergence areas (Table). This takes a chance to use design of convergence and divergence areas as an indicator of soil complex for terrains with available topographic data but inaccessible soil information. For instance, one can compile a graphic database of key areas (as Table) for soil mapping of poorly investigated terrains. This type of database was developed previously for arid plain and mountainous regions of the Middle Asia and Kazakhstan (Stepanov, 1989).

Fragmentation of the terrain into segments and their merging into 'clusters' can be considered as a formalised protocol for determination of borders of areas marked by dominant soil complexes and rocks. This protocol can be useful in soil mapping, since it allows one to reduce a subjectivity of mapping, and to display clearly relationships in the system 'geology–topography–soil' on a map. Design of convergence and divergence areas creates unique visual icons both for relief types, and for related soil complexes and rock ages. Therefore, it can be reasonable to place designs of convergence and divergence areas typical for different soil complexes into legends of soil maps (Stepanov, 1989).

Why do segments marked by individual designs of convergence and divergence areas arise as a result of intersections of ring structures? We can propose the following hypothesis. An initiation of a ring structure of any origin can anisotropically change some mechanical properties of rocks situated within and around the structure. In particular, new fracture systems can rise. Their strike azimuths and intensity can depend on some parameters of a process led to the occurrence of the ring structure (e.g., an applied shock of a meteor) and initial properties of rocks. Intensity and strike azimuths of the fracture system can influence intensity and directivity of subsequent

weathering and erosion, and hence relief and soil development. Let there be two nonoverlapping ring structures marked by two different fracture systems. Courses of weathering and erosion may also differ within these structures. This may lead to development of some individual properties of topography displayed on k_h maps as individual designs of convergence and divergence areas. In intersection of two ring structures, there is a segment whereas the fracture system of the first ring structure overlaps the fracture system of the second one. In other words, the third fracture system arises. Its parameters may control individual topographic properties for this segment, which are displayed on k_h maps too. Along similar lines, a case of intersection of three or more ring structures can be explained.

CONCLUSIONS

1. Let there be two ring structures defined by two circles with radiuses of R_m and R_n. These circles border two heterogeneous subsets M and N of convergence and divergence areas. Let the circle with the radius of R_n intersects the circle with radius of R_m. This brings into existence a segment situated within the both ring structures. This segment includes a subset L of convergence and divergence areas. A design of the subset L differs from designs of both the subset (N–L) and the subset (M–L). Segmentation of the subset M can be observed until a subset K can be separated. For a given scale, this subset is marked by a homogeneous design of convergence and divergence areas.

2. Different groups of subsets K can be merged into rather extended 'clusters' with dominant soil complexes and rocks.

3. Fragmentation of the terrain into segments and their merging into 'clusters' is a formalised protocol for determination of borders of areas marked by dominant soil complexes and rocks. This protocol can be useful in soil mapping, since it allows one to reduce a subjectivity of mapping, and to display clearly relationships in the system 'geology–topography–soil' on a map. Design of convergence and divergence areas creates unique visual icons both for relief types, and for related soil complexes and rock ages.

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