The elevation and its distribution in geomorphological regions of the European Russia

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Abstract. Spatial differences of elevation were analysed by side of view of geomorphological boundaries on the European Russia territory. Geomorphological pattern of the studied territory was taken from Geomorphological Map of the USSR at scale of 1:2 500 000. There 2401 fragments for combinations of 58 types of structural landforms and 22 types of sculptural landforms were allocated. The elevation values computed by digital elevation model (cell size – 200 m, number of cells – 322M) based on SRTM (south of 60 nl.) and GDEM 2010 (north of 60 nl.) resampled data. It was founded that some types of structural (16 types) and sculptural (6 types) landforms located in the relatively thin intervals of elevation. Using of elevation above sea level is needed for effective automatic recognizing these landform regions.

1. Introduction
Geomorphometric data can give possibility to classification of landforms by characteristics of the Earth surface geometry. There is a lot of articles illustrating this approach [1, 2, 3, 4, 5]. Some regions with different landform origin have non-equivalent values of elevation and its distributions. Not all differences of landforms can be recognized by single parameter. However, there are little publications with assessment of representativeness of even simple geomorphometric parameters such as elevation. This paper is aimed at to identification of landform types subdivided using averages and ranges (standard deviation) of elevation. Back in the late 19th century Lapparent used statistical distribution of elevation as indicator of geological structure [6]. Then some papers were written on the problem of analysis and interpretation of the statistical distributions of terrain [7, 8, 9, 10]. There are premises for using other geomorphometric parameters (for example, some focal statistics [11, 12]) for rising demarcation effectiveness, but in the paper we will limit ourselves only by this weightiest parameter.

2. The problem statement
Soviet geographers I.P. Gerasimov and J.A. Mescherikov in the 1946 offered new way for hierarchically landform classification. They recognize three levels of the Earth surface organization which Gerasimov named by terms: "geotextures", "morphostructures" and "morphoscultures" [13]. These levels were actively used as units for geomorphological mapping in the USSR and Russia in the second half of the 20th century and at present. The base of this approach is dividing of the Earth surface by leading geomorphological processes on each hierarchical level. For geotextures they are planetary and...
geotectonic processes, for morphostructures they are mainly structurally-initiated endogenic processes. And for morphosculptures they are almost exclusively, exogenic processes.

In the study there was used geomorphological pattern of the European Russia from famous soviet Geomorphological Map of the USSR at the scale of 1: 2 500 000 [14] completed in 1981. The whole area of the Soviet Union included sites of 149 types of morphostructures and 32 types of morphosculptures. The territory of the European Russia included sites of 58 types of morphostructures and 22 types of morphosculptures. This scheme is mainly given in the tables 1 and 2.

Table 1. Typology of structural landforms on the European Russia territory from Geomorphological Map of the USSR (fragment).

| Geotectonic region | Subregion | General condition of landform development | Type of structural landforms |
|--------------------|-----------|------------------------------------------|------------------------------|
| 1. Platform plains | 1.1. Socle plains, tablelands and mountain massifs of Pre- Paleozoic shields with strong recent upwarp and block uplift | 1.1.2. Structural-denudational | Semiburied step plains |
|                    | 1.2. Socle plains, island low-mountain relief, massifs and ranges of platform basement protrusion | 1.2.1. Structural-denudational | Semiburied plains and chains of hills |
|                    | 1.3. Plains and plateaus Pre- Paleozoic and Phanerozoic plates was subjected of resiliency deformation with uplift and subsidence | 1.3.1. Layered and denudation plains and plateaus with predomination of recent uplift | Plains and chains of hills |
|                    | 1.3.2. Layered and accumulation plains generally created by recent subsidence built by loose Neogene and quaternary rocks | 1.3.2.1. Layered and accumulation | Table and step plateaus built by sediment deposits |
|                    | 3. Orogens | 1.3.2.2. Accumulation | Stepped plains built by sediment deposits |
|                    | 3.1. Mountain structures updated by recent block uplift built by consolidated rocks of Pre- Paleozoic and Paleozoic folding | 3.1. Structural-denudational mountains | Sloped plains built by sediment deposits |
|                    | 3.2. Mountain structures created by recent socle and block uplift and fold deformation built by different consolidated sediments of Alpine folding | 3.2.1. Structural-denudational mountains | Sloped, partially stepped plains built by sediment deposits |
|                    | 3.3. Mountain structures created by recent uplift and volcanism | 3.2.2. Intramontane lowlands | Volcanic mountains and high plateaus |
|                    | 3.3.1. Areas of Cenozoic volcanism of Alpine folding | 3.2.3. Intermontane lowlands | |
Table 2. Typology of sculptural landforms on the European Russia territory from Geomorphological Map of the USSR.

| Condition of development | Forms created by processes of... | Type of sculptural landforms | Area, tous. sq. km |
|--------------------------|----------------------------------|-----------------------------|--------------------|
| 1. Azonal                | 1.1. controlled by structural condition | 1.1.1. erosion and complex denudation | Hill lands | 4.9 |
|                          |                                  |                             | Ouval lands | 661.2 |
|                          |                                  |                             | Hill and ouval lands | 85.3 |
|                          |                                  |                             | Ridge lands | 11.9 |
|                          |                                  |                             | Ridge and ouval lands | 121.2 |
|                          |                                  |                             | Table and step lands | 101.7 |
|                          |                                  |                             | Flat and weak wavy lands | 390.9 |
|                          |                                  |                             | Mountain (incised) lands | 238.5 |
|                          |                                  |                             | Plateaus (incised) lands | 68.5 |
|                          | 1.1.2. complex denudation |                             | Sloping relief (morphologically diverse) | 54.0 |
|                          | 1.1.3. accumulation of different genesis sediments | Flat or weak wavy lands covered by quaternary layers of different origin | | |
| 2. Zonal                 | 2.1. inherited-developing and modern | 2.1.1. complex arid denudation | Flat or weak wavy lands | 48.7 |
|                          |                                  | Hills, ridges and ouvals (hummocky terrain) | 12.9 |
|                          |                                  | Table and step lands | 50.0 |
|                          |                                  | Rolling and sloping hill lands, smoothed | 50.2 |
|                          | 2.2. relict (generally quaternary) | 2.2.1. exaration | Ridge and hill lands | 178.8 |
|                          | 2.2.2. cryogenic and glacial morphogenesis | | Mountain relief with cryogenic and glacial moderation | 59.1 |
|                          | 2.2.3. glacial and fluvioglacial accumulation | | Rolling and sloping hill lands of moraine plains | 625.3 |
|                          |                                  | | Ridge and hill lands of marginal and radial postglacial areas | 102.9 |
|                          | 2.2.4. glacial accumulation and further erosion | | Hill and ouval lands | 94.4 |
|                          | 2.2.5. fluvioglacial accumulation and further erosion | | Ouval lands | 112.5 |
|                          |                                  | | Sloping ouval lands | 178.0 |

3. Results and discussion

Structure. The localisation of structural regions in thin elevation interval was estimated as quotient of standard deviation and median of elevations. Only one region has the quotient less than 0.1 – it is "table and step plateaus built by sediment deposits" (subdivision 1.3.1.1). The median elevation here is 264 m, but standard deviation is 13 m only. This region is strongly localised in the elevation interval. The region is represented by three sites in the buffer ring of the studied area – in the Kostanay Region of Kazakhstan.

The six regions have the quotient more than 0.1 but less than 0.2: they are "semiburied step plain" (subdivision 1.1.2), "sloped plain built by sediment deposits" and "sloped, partially stepped plain built by sediment deposits" (subdivision 1.3.1.1). "layer plateau built by sediment deposits" (subdivision 1.3.1.2), "sloped plain" (subdivision 1.3.2.1) and "fold monoclinal ranges and plateau" (subdivision 3.2.1.). The first region is represented by only one site placed in the Velyka Novosilka Region of Donetsk Oblast in the Ukraine. Median elevation of the semiburied step plains is 159 m and standard deviation is around 17 m. The second region is placed in the Central Russian Upland and its southeastern part known as the Kalach Upland, in the northern part of the Volga Upland and part of Bugulma-Belebey Upland. Median elevation of region is 196 m and standard deviation is 37 m. The third region is placed in Smolensk and Moscow Upland, some sites are in the Cis-Ural territory. Median elevation of region is 190 m and standard deviation is 34 m. Last defined regions are similar to their origin. The region of
layer plateaus is located only in the Aktobe and Kostanay Regions of Kazakhstan with median elevation 242 m and standard deviation 29 m. The two regions have strong differences with previous divisions. Sloped plains from subdivision of 1.3.2.1 locates exclusively on the eastern flank of Donetsk coal basin (median elevation – 157 m, standard deviation – 25 m). And the fold ranges and plateaus are located in the far south of the studied area – in the Lesser Caucasus territory (median elevation – 358 m, standard deviation – 47 m). All six regions cover relatively small areas and haven't any morphometric diversity.

The nine regions have the quotient more than 0.2 but less than 0.3. Two of them are plains and chains of hills (included semiburied and opened landforms). The regions are represented by territories of Donetsk and Timan Ridges and also by some near-Ural areas. Median elevation of semiburied plains is 174 m and standard deviation is 39. The same parameters of opened plains are 305 m and 90 m.

The largest median elevation value (more than 2900 m) typical for structural region of volcanic mountains and high plateaus includes two sites of Keli (Qeli) Highland and Mount Kazbek. However, the region has quotient 0.22 at the standard deviation of elevation of 640 m. High-mountain grabens (for example, in the Great Caucasus) on the studied area locates on 2400 m above sea level at the elevation standard deviation of 599 m. The sloped plains with the sediment cover or without it (socle plains) are placed in piedmonts of Lesser Caucasus and Trans-Ural. They have equivalent elevations. The stepped plains of Pechora river basin have median elevation of 118 m and standard deviation of 32 m. And the last region is "sloped plains built by sediment deposits" (subdivision 1.3.1.1.). The region is represented by Valdai Hills with the median elevation of 187 m and standard deviation of 53 m.

The regions with the quotient more than 0.3 are considered to be not representative of using the elevation intervals as diagnostic attribute. Short data on characterized sixteen regions is given in the table 3. The geographical distribution of described structural regions is shown on the figure 1 (a).

**Sculpture.** We used the same technique for assessment of localization of morphosculptural regions in the elevation intervals as in the case of morphostructures. The threshold value of quotient was taken as 0.3 again. It is important that the values of quotient less than 0.1 were not found. It may mean that some structural regions fix more finely in the elevation intervals than sculptural regions, and elevation field was set by structural conditions in general.

The least deviations of elevation characterize areas created by processes of complex semiarid and arid denudation. Authors using geomorphological map of the USSR, singled out hummocky and flat (or weak wavy) terrains. The first have median elevation of 312 m and standard deviation of 37 m. Flat or weak wavy lands have surprisingly bigger value of standard deviation — 48 m (at the median value of elevation — 295 m).

Four morphosculptural regions relate with the areas of Pleistocene glaciations. Region of hill and ouval lands is located on the territory of old middle-Pleistocene glaciations (Moscow ice age, synchronically to Riss ice age in the West Europe). Hilly (concentric) landforms are common in the band of marginal zone of the glacier. Ouvals and intermediate landforms from hills to ouvals are common outside glacier zone (periglacial band). It has better erosional moderation and large topographical dissection. Band of hilly lands has values of median elevation of 191 m and standard deviation of 36 m. Intermediate zone of sloped ouvals is characterized by values of 165 m and 32 m, respectively. Zone of typical ouvals is characterized by values of 182 m and 53 m respectively (essential erosional dissection).

One morphosculptural region is located in the area of the Valdai ice age glaciers ("ridge and hill lands of marginal and radial postglacial areas"). This territory is replete with such landforms as drumlins and eskers. Median elevation here is 161 m and standard deviation is 48 m. Short data on characterized six regions are given in the table 4.
### Table 3. Morphostructural regions of European Russia located in the thin elevation intervals.

| No | Region | Median elevation | St. deviation of elevation | Quotient | Geographical location of examples |
|----|--------|------------------|---------------------------|----------|----------------------------------|
| 1  | 1.3.1.1. table and step plateaus built by sediment | 264 | 13 | 0.05 | Kostanay Region of the Kazakhstan |
| 2  | 1.1.2. semiburied step plains | 159 | 17 | 0.11 | Donetsk Oblast in the Ukraine |
| 3  | 1.3.1.2. layer plateaus built by sediment deposits | 242 | 29 | 0.12 | Aktobe and Kostanay Regions of the Kazakhstan |
| 4  | 3.2.1.2. fold monoclinal ranges and plateaus | 358 | 47 | 0.13 | Lesser Caucasus |
| 5  | 1.3.2.1. sloped plains | 157 | 25 | 0.16 | eastern flank of Donetsk coal basin |
| 6  | 1.3.1.1. sloped, partially stepped plains built by sediment deposits | 190 | 34 | 0.18 | Smolensk and Moscow Upland and some Cis-Ural Uplands |
| 7  | 1.3.1.1. stepped plains built by sediment deposits | 196 | 37 | 0.19 | Central Russian, Volga and Bugulma-Beleby Upland |
| 8  | 3.3.1.1. volcanic mountains and high plateaus | 2906 | 640 | 0.22 | Keli (Qeli) Highland and Mount Kazbek |
| 9  | 1.2.1. semiburied plains and chains of hills | 174 | 39 | 0.22 | East of Donets Ridge |
| 10 | 3.2.2. grabens | 2408 | 599 | 0.25 | Valleys on North Slope of Greater Caucasus |
| 11 | 3.2.3.2. sloped plains | 237 | 62 | 0.26 | Lesser Caucasus |
| 12 | 3.1.1.1. socle sloped plains | 238 | 63 | 0.26 | Central and North Trans-Urals |
| 13 | 1.3.1.2. slightly sloped plains and plateaus built by sediment deposits | 156 | 42 | 0.27 | Uppers of North Dvina river basin |
| 14 | 1.3.2.2. stepped plains | 118 | 32 | 0.27 | Pechora river basin |
| 15 | 1.3.1.1. sloped plains built by sediment deposits | 187 | 53 | 0.28 | Valdai Hills |
| 16 | 1.2.2. plains and chains of hills | 305 | 90 | 0.30 | South Trans-Urals, North Cis-Ural and part of Timan Ridge |

### Table 4. Morphosculptural regions of European Russia located in the thin elevation intervals.

| No | Region | Median elevation | St. deviation of elevation | Quotient | Geographical location of examples |
|----|--------|------------------|---------------------------|----------|----------------------------------|
| 1  | 2.1.1. Hills, ridges and ouvals (hummocky terrain) | 312 | 37 | 0,12 | Southeast Ural |
| 2  | 2.1.1. Flat or weak wavy lands | 295 | 48 | 0,16 | Southeast Ural |
| 3  | 2.2.4. Hill and ouval lands | 191 | 36 | 0,19 | Line Smolensk - Syktyvkar |
| 4  | 2.2.5. Sloping ouval lands | 165 | 32 | 0,19 | South of line Smolensk - Syktyvkar |
| 5  | 2.2.4. Ouval lands | 182 | 53 | 0,29 | South of line Smolensk - Syktyvkar and Ural piedmonts |
| 6  | 2.2.3. Ridge and hill lands of marginal and radial postglacial areas | 161 | 48 | 0,30 | North-West of European Russia |
Figure 1. Types of morphostructures (a) and morphosculptures (b) of the European part of Russia localized in relatively thin intervals of elevation.

The geographical distribution of described sculptural regions is show on the figure 1 (b). Thus we found out that:

1. Location of some types of morphostructures and morphosculptures are characterized by relatively thin intervals of elevation (quotient of standard deviation and median of elevations less than 0.3 in the article). Sixteen types of structural landform regions from fifty eight types on whole studied area have corresponding values of the coefficient. And six types of sculptural landform regions from twenty two types on whole studied area have corresponding values of the coefficient;

2. Structural landforms have mainly lower values of quotients than sculptural landforms. Consequently, the elevation field is due to the structural plan of the territory in general;

3. Relatively low dispersion of elevation corresponds to stepped and sloped plains and plateaus and, in a less degree, to some mountain structures such as grabens and high volcanic plateaus. In the case of sculptural landforms, low dispersion of elevation corresponds to the arid climate planation surfaces and to areas of typically post-glacial landforms;

4. The parameter of elevation can be used for automated classification of DEM and recognizing of described landform types.

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