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NEOTECTONIC FACTORS AFFECTING GEOMETRY OF PLAINS

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ABSTRACT

The objective of this research is to expand our understanding of how endogenous processes influence development of erosion systems. Study of the East European Plain allowed the authors to collect a large amount of data, which show that the life cycle of erosion system is controlled not only by the 'obvious' factors (runoff volume, slope, rock type, etc.) but also by large-scale processes forming the face of the Earth. Such processes, according to the authors, first of all, involve tectonic events that are manifested by vertical movements of crustal blocks and account for formation of uplands and slopes.

The authors used a complex technique to check their assumptions, including methods of qualitative and quantitative evaluation of upper crust deformations using archive aerial and satellite images (evolution or degradation of more than 200 gully systems were observed through a series of aerial and satellite images taken in 1953, 1980 and 2008) and morphometric analysis of digital elevation models to create a model of neotectonic activity in the studied territory (hilly plateau in the east of the East European Plain).

The authors also found that there is a direct association between neotectonic activity and modern geodynamics: areas with stable or constantly degrading erosion systems are related to neotectonically calm territories, while areas with active dynamics are usually located in close proximity to the medium- and high-amplitude neotectonic uplifts.

Keywords: geometry of plains, neotectonics, erosional patterns

INTRODUCTION

Worldwide experience has shown that erosional systems in different parts of the world evolve in a similar way. In its early stages, ravine grows very fast and may be able to create many little side tributaries; then its longitudinal profile acquires a stable form, erosional processes become less active, and the ravine is gradually turned into a gully. But why is it that secondary young ravines often occur in old gullies? Or why the ravine, which showed every sign of being settled to a steady state, suddenly begins to grow or forms tributaries?

And there are some other questions. Why in some cases, no matter how thoroughly gully control was organized, and whatever antierosion measures were taken, ravines just keep growing, while in other places they are stable over time, even in the face of intensive plowing? All these questions are important both from a cognitive, and a practical viewpoint: every year, ravines cause enormous damage to both human economic activities, and landscape ecology as a whole.

A common problem associated with gullies is that the vast majority of researches focuses on local areas (covering 2–3 gullies), and observing time is very limited. [1] New knowledge can be acquired only by expansion of the studied area and the time frames. It is clear that such an expansion can be achieved by comparison of the data for various periods, covering hundreds (or even thousands) of local erosion systems. This is exactly the sort of a task that geographic information systems (GIS) are very good at. Also, high resolution remote sensing data will come in very handy, if they are obtained for the same area, but at different times.

We used archive aerial photos and satellite images as the primary data source, while GIS was the main operating tool. The main goal of our research is to obtain some new information about the processes that influence the landscape geometry, as well as to develop new methods of remote sensing data handling for purposes of geodynamic studies.

MATERIALS AND METHODS

Relief is a striking and vivid demonstration of the earth's crust evolution process. Its geometry is determined by two factors and their interaction – tectonics and erosion. These relief-forming processes are usually considered and studied as independent phenomena, but it is necessary to take into account both of them in order to get better understanding of how each type of relief was formed. The object of this study is a tectonic relief. 'Tectonic relief' refers to any tectonic movements, which result in contrasting landforms on the earth's surface. No matter how complex, individual tectonic landforms are always determined by two types of movement – lifting and lowering. Even in the case when some horizontal movement is the core tectonic process, it will be seen at the surface only if there is also a change in hypsometric date. In our case, the problem is complicated by the fact that tectonic relief was studied in the setting of a plain, where the neotectonic processes have substantially lower rates and, landforms are less contrasting.

We used a complex technique, including methods of qualitative and quantitative evaluation of upper crust deformations using archive aerial and satellite images, as well as morphometric analysis of DEMs to create a model of neotectonic activity in the studied territory. Comparison of qualitative and quantitative characteristics of crustal movements for different time intervals (from ~ 10 to ~ 1,000,000 years) can help to get an idea of relationship between modern geodynamic phenomena and neotectonic processes.

A hilly plateau in the east of the East European Plain (the coordinates of the center are: WGS 51°28'43"W 54°46'17"N) was chosen as the research object. This is an area (1370 sq.km) with a highly developed agricultural infrastructure and intensive oil production. The project uses data from aerial photographic surveys conducted in 1953 (scale – 1:17,000; altitude – 1,100 m) and in 1980 (scale – 1:50,000; altitude – 7,000 m), as well as WorldView satellite data for 2008 (panchromatic band; spatial resolution of 60 cm). ArcGIS 10 (ESRI, USA) and ERDAS Imagine 2010 (ERDAS, USA) were chosen as data processing software.

Processing of aerophotos taken in 1953 and 1980 was rested on their ordinary adjustment to the WorldView images, i.e. to geometric correction and coordinate system determination. Geometric correction was performed in IMAGINE AutoSync, and the average error was 6.5 m. Then, all the transformed images and satellite images were integrated in one geoinformation project, where they were compared and analyzed.

Morphometric analysis of digital elevation model (DEM) was used to create a model of neotectonic activity. Morphometric method is based on the assumption that the earth's crust movements, interacting with exogenous processes, overcome their smoothing effect and reflect in modern relief and river systems. [2] Morphometric analysis allows dividing the DEM into several components (levels, or morphometric surfaces of different orders) corresponding to certain stages of neotectonic history. In this case, the difference between isobase surfaces of lower orders was the object of interest. Isobase surface is a surface integrating local base levels of erosion. Isobase surfaces are distinguished by their orders in accordance with the stream valley order. Valleys of the 1st order are those, which do not enter any other valley; valleys of the 2nd order are formed by two merging valleys of the 1st order; 3rd-order valleys are formed by two merging valleys of the 2nd order, etc. [2] Isobase surface of the 1st order integrates local bases of erosion of all orders; isobase surface of the 2nd order integrates local bases of erosion of the 2nd, the 3rd and all the other higher orders; isobase surface of the 3rd order integrates local bases of erosion of 3rd and all the other higher orders, etc. Isobase surfaces of lower orders just slightly differ from the surface relief. Without any tectonic movement, relief would be eroded to the 2nd order isobase surface at the beginning of the erosion cycle, and then it would degrade to the 3rd order surface, and so on. Valleys of the 1st order in lowlands are small channels cutting the slopes and hollows on watersheds. Hollows then turn into ravines or gullies, which subsequently become rivers. Under mild climate conditions, the river valleys with a constant water flow are usually of the 3rd or the 4th order. In the1st and the 2nd order valleys water streams are only temporary. It also has to be considered that some gullies are rather young (i.e. appeared in Holocene). Therefore, we can assume that the difference between isobase surfaces of the 1st and the 2nd order shows the direction and intensity of tectonic movements that occurred in the time period between modern and late stages of the relief evolution (until Pleistocene, ~1.6 million years [3]). Fragment of such difference obtained for the studied area is shown in Figure 2. Calculation and further processing of isobase surfaces was conducted on the basis of a digital terrain model (scale of 1:200,000) by the method described in [4].

RESULTS

65 aerophotos taken in 1980 and 186 aerophotos taken in 1953, along with WorldView images of 2008 were used for a comparative analysis.

Comparison of multi-temporal data revealed that relief may undergo significant changes in 55 years. Part of the changes has a clear anthropogenic origin (construction of dams, canals and rivers redirection). But the rest of changes can be certainly related to modern geodynamics. It is also known that if the area experience upward movements, its landforms will acquire specific features [2], i.e.: absolute elevations will increase; rivers and other waterways will straighten or assume sharp turns (up to 90 degrees); detrital material transferred by the river will significantly increase in volume; gully systems will grow rapidly (ravines will enlarge their depth and linear dimensions, and small channels will turn into ravines). In the case of tectonic subsidence, erosion processes fade, ravines start to fill up with overgrown vegetation, small permanent and temporary waterstreams disappear, and large ones begin to meander.

All of the above-mentioned characteristic features of geodynamic processes were found within the research territory. Figure 1 shows several scenarios of erosion system evolution.

Careful comparison of multi-temporal data for 246 gullies and gully systems was performed. Unfortunately, in some cases it was impossible to determine clear trends (for example, there is no reliable way to trace the growth of gully systems in forest areas). Also, some information has been lost due to the low quality of several aerophotos. Nevertheless, it was possible to make a number of interesting observations and to identify dozens of areas with vivid modern geodynamics (both positive and negative). 54 out of 246 gullies show evidence of active growth, 70 gullies experience degradation, and 122 erosional systems remain unchanged over the last 55 years.

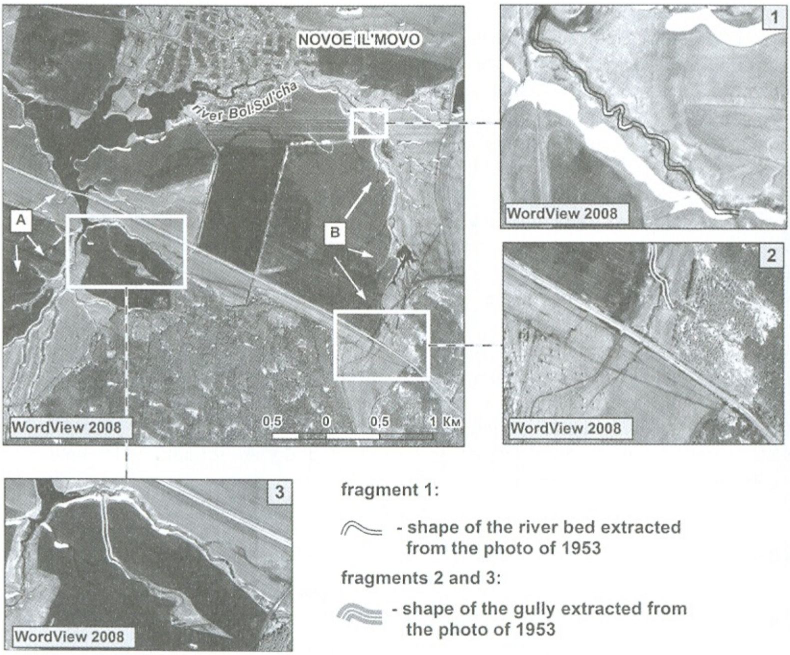

Fig.1. Comparison of remote sensing data obtained for different time periods. Monitoring of two erosional systems – A and B – was conducted: fragment 1 shows straightening of the river bed; fragments 2 and 3 show growth of gullies during 1953–2008.

DISCUSSION

Speaking generally, the rate of gully growth should not be considered as a direct indication of geodynamic activity, since development of a gully is a multifactorial process, and the role of these factors can vary significantly depending on gully evolution stage. But it is certainly reasonable to use the growth rate as an indirect sign.

Studies on erosion processes carried out on the territory of European Russia [5, 6, 7, 8] over the past 70 years indicate that the average life period of ravines is approximately 100-150 years, after which they turn to gullies. It is believed that modern erosion processes were triggered by human activities. After receiving the initial impulse, erosion develops very rapidly over the next 15-20 years. Then, if all the factors influencing growth of ravines stabilize, erosion will slowly fade. On the other hand, there are many examples of ravines, which passed through different, non-traditional, stages during their evolution. [5, 6, 7, 8] These examples show that the life cycle of erosion system is controlled not only by the 'obvious' factors (runoff volume, slope, rock type, forest coverage, snow melting, intensity of plowing, etc.) but also by large-scale processes forming the face of the earth. Such processes, first of all, involve tectonic events that are manifested by vertical movements of the crustal blocks and account for formation of uplands and slopes.

In search of the causes for erosion activation and decay, scientists have studied dependences between growth of gullies and meteorological and other parameters. But, as pointed out in [6], the correlation coefficients in most cases appeared to be rather low (<0.5), except for dependence on soil erodibility. Field observations and simulation results [8] lead to the conclusion that growth rate and size of the ravines are influenced mainly by the base level of erosion and the slope. According to A.P. Dedkov et al. (1997), anomalies in the gullies evolution are well correlated with abnormal volumes of detrital material in the rivers of the East European Platform [5], but this correlation is not absolute. But with the other conditions being equal, the flow rate and its transporting capacity also depend on the base level of erosion and slope geometry. With a steep slope and deep erosion, ravine head can approach the watershed so close that zone of no erosion will vanish almost completely. It should be also kept in mind, that the natural climate variations and total moisture content determine sea level fluctuations. But the changes in slope geometry and local base level of erosion can only be explained by neotectonic processes.

The ratio between modern geodynamics and neotectonic movements can be evaluated through comparison of the remote sensing data with the morphometric analysis results. Figure 2a represents a fragment of the neotectonic activity map, created for the studied area, along with the distribution of areas with currently active geodynamic processes (calculated in accordance with amplitudes of the vertical movements) (Fig. 2b). The underlying raster image represents a difference between the isobase surfaces of the 1st and 2nd orders. As mentioned before, this type of morphometric surface shows direction and intensity of tectonic movements that occurred during the last stages of relief evolution. Therefore, this surface reflects the current geodynamic conditions. Because this surface has been calculated on the basis of DEM with a scale of 1:200,000, the neotectonic structures here are considered regional. The diagram (Fig. 2b) shows the average amplitudes of the vertical movements within the polygons of each type, representing the areas where ravine heads have been studied.

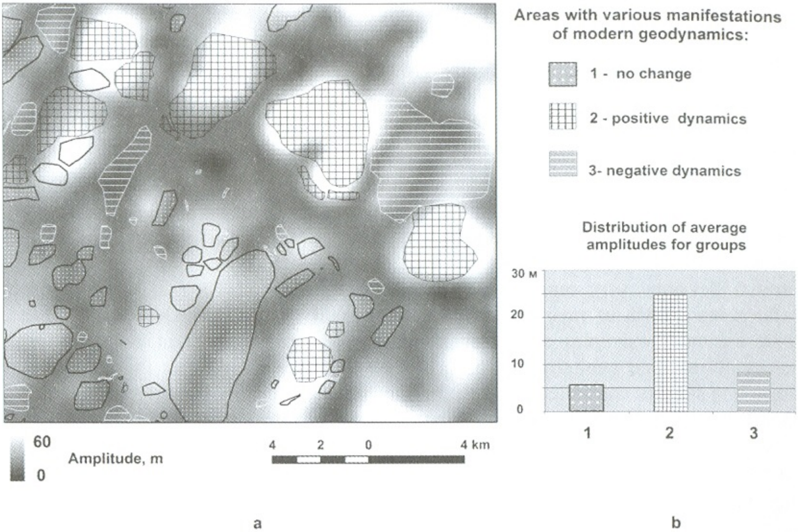

Fig. 2. Comparison of modern geodynamics manifestations with signs of neotectonic activity within the study area.

It is obvious that there is a direct association between neotectonic activity and modern geodynamics: areas with stable or constantly degrading erosion systems are related to neotectonically calm territories, while areas with active dynamics are usually located in close proximity to the medium- and high-amplitude neotectonic uplifts. Besides giving further evidence for the basic principles of the modern landforms formation theory, this fact can be also used for purely practical purposes. For example, it is virtually certain that, there are no geological prerequisites for growth of gullies within the territories of low-amplitude neotectonic movements (with the other conditions being equal), so one can keep growing crops without fear of soil devastation. On the other hand, deforestation of actively upraising watersheds can lead to rapid growth of gullies and soil degradation.

CONCLUSION

Technique described above can be applied to any part of the platform with well-developed erosion system. The main advantage of this technique is that the analysis results are represented in a form of surfaces, in contrast to conventional methods defining values only at points or along profiles. It also would be interesting to obtain such results for other areas. Some more information would allow to speak confidently about the nature of the relationship between modern geodynamic and neotectonic processes which, according to the authors, definitely exists.

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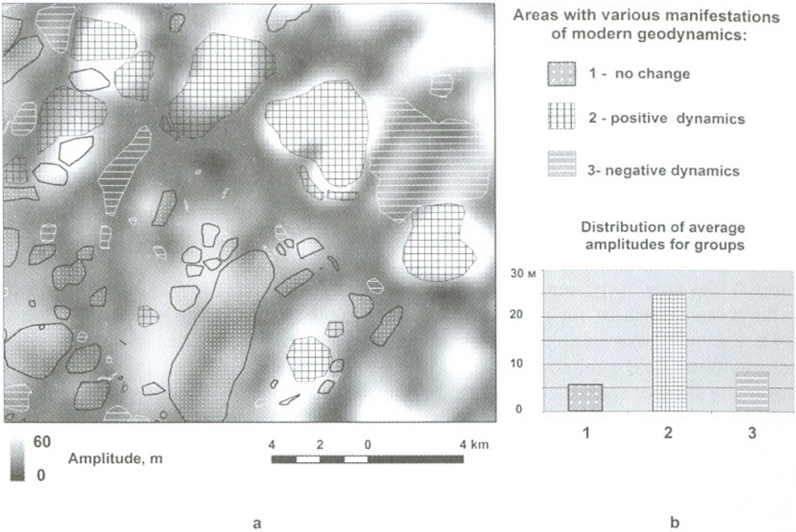

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