# Morpho-orographic and morpho-climatic factors of exomorphic dynamics of denudation platform plains of Kazakhstan

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**Abstract.** Detection of factors of formation of environmental geomorphologic systems (EGS) is based on studying literature and source maps. This article is the first one that treats morpho-orography and morpho-climatic singularities as main exodynamic factors of formation and differentiation of morpho-litogeneous systems within the denudation platform plains of Kazakhstan (Central Kazakhstan). According to the purpose and the objectives of the study, the morphological analysis of geographic and geological maps of the 1:500,000 scale was carried out, geological and geomorphological profiles-sections were made, perennial field studies were carried out, and the climatic indicators in main geomorphological districts of Central Kazakhstan were compared. The climatic indicators were taken from general climatic reports by weather stations of the Karaganda region. The originaldedicated map was made up based on the analysis of general geographic and dedicated maps, the results of study of scientific literature and field studies, and the decoding of satellite images. Make-up of the cartographic items and the database was carried out using geoinformation technology based on MapINFO 9.5, ArcGIS 10.1, and the ArcMAP module.

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## Introduction

Development of geomorphology in the second half of XX century and the beginning of the XXI century is remarkable for the scope of studied issues – from the analysis of requirements of the assigned tasks through the analysis of probabilistic methods of their solution and consequences of changes of the habitat to probabilistic estimates and forecast. Therefore, increasing strengthening of the demand in new knowledge about the terrain as the basis of the human ecosystem is observed. The basis of the human habitat are territories, the geomorphological conditions of which comply with certain socio-strategic (strategy is understood as a system of views and behavioral standards of groups of people in case of dangerous natural, anthropogenic, or other incidents - R.B.) and socio-economic requirements.

Geomorphological conditions of the habitat are the terrain morphology, the nature, the intensity, and the orientation of exodynamic processes, the structural and lithological singularities of surface buildups. Their spectrum and requirements to them change depending on the type of economic activity of humans. However, any economic activity changes the initially selected "optimum" conditions – the morphological characteristics of the terrain, the nature and the progress of the exodynamic processes.

The indicator and at the same time the regulator of exodynamic processes are the morphology of the terrain and the lithological substrate and its condition. Their certain combinations with each other can serve as the basis for understanding the nature, the progress, and the orientation of the exomorphic dynamics. The boundaries of displays of the exodynamic processes can be structural, geological (the differences are in the structure of the underlying buildups), morpho-orographic (the differences are in the position and the structure of macro- and mesoforms of the terrain), hydrogeological (the type of mineralization and the groundwater depth level).

The terrain, being a self-developing system, changes depending on the changing conditions of the external (endogenous and exogenous) environment. In the circumstances of the denudation platform plains of Central Kazakhstan, the role of the endogenous factor (the seismotectonic activity) is low and its role in the study of the environmental and geomorphological correlations is not rather obvious. Therefore, among the two elements of the environment, the exogenous one is the main one; its content is determined by three factors: the litogeneous (the structure and the singularities of the surface buildups, the morpho-orography of the terrain), climatic (determining singularities and

diversity of local physical and geographic conditions), and anthropogenic ones. The dynamism of the litogeneous factor in subarid and arid regions of Central Kazakhstan (the structure and the singularities of the surface buildups, the extent of disaggregation and transformation of the properties of rocks, the displays and the increase in the systems of fissility, the spatiotemporal changes of the morphographic and morphometric characteristics of the terrain) is determined by the climatic (changes of the hydrologic pattern, the water and heat balance, the aerodynamics, the augmentation of the meso- and microclimatic differentiation etc. in the circumstances of the strengthening aridity of the modern climate) and anthropogenic factors. In its turn, the spatial differentiation of meteoclimatic indexes with all expected impact on the exomorphogenesis depends on the morpho-orographic pattern of the surveyed territory.

**Methodology and materials**

Study of the role of the morpho-orographic and the associated with it morpho-climatic factors in the formation of the modern terrain pattern and the dynamics of exomorphogenesis in the territory of Central Kazakhstan has been carried out for the first time. This study being the main objective of our work has determined the direction of the bibliographic search and the analysis of literary sources [1,2,3,…,12], the content of perennial field surveys (1986-2013), the selection of key plots with account of the economic human activity, and the list of necessary cartographic material and the pattern of the scientific search.

When carrying out the work, we based on usage of the comparative geomorphological, and cartographic analyses, the systemic analysis of the terrain, the study of the satellite images (the Landsat-7 satellite images taken in 2009 and 2012) and the field nature observations, the analysis of topical (geological and geomorphological) and general geographic maps of large scale - 1:500,000 and 1:100,000 issued in various years (1972, 2010), the analysis of morphometric and graphic buildups by topographic maps, and the statistic data of sociological polls and the KazGidroMet Institute of the Republic of Kazakhstan.

Make-up of cartographic items and the database was carried out using the geoinformation technology based on MapINFO 9.5, ArcGIS 10.1, and the ArcMAP module.

**Body of the work**

In some geomorphological works, the morpho-orographic and morpho-climatic factors (the spatial orientation of large shapes of the terrain, their morphology, exposition of slopes as well as differences of the meteo-climatic indexes associated with them) are treated as the most important elements of the exomorphic dynamics of the earth surface [1,2,3,…,12]. In the presented article, these factors are also treated as the main ones in formation and differentiation of the environmental and geomorphological systems. The Kazakhstan shelf represented by the territory of Central Kazakhstan is generally a base-leveled bench of the epi-Paleozoic plate with differentiation for accumulative depressions, denudation uplands, and low hill and island elevations. Bounded on three sides by morphologically distinct troughs (in the north - the West Siberian Basin and the valley of the Irtysh River, in the west – the Turgay trough, and in the south - by piedmont troughs), the length of Central Kazakhstan from the west to the east is more than 1,200 km, and from the north to the south – about 600-700 km. The overall roof elevation, the layering, the prevalence of datum levels over 500 m across the terrain, and the knoll-type fraction constitute the characteristic feature of its morphology. The formation pattern and the originality of the terrain of Central Kazakhstan is determined by a battery of causes: it is the ancient structural plan, the duration of the continental development of the terrain (starting from the Carbonic period) against the background of slow tectonic uplift of the shelf and the lithology of mountain rocks, which have determined the layering of the terrain and its modelling in accordance with the type and the nature of exodynamic processes in the circumstances of the subarid and arid climate. The layering of the terrain is determined by the newest activation of Paleozoic structures (caledonides and hercynides) along the lines of the controlling them large faults of the foundation. Faulting has very various strikes and density, but northwestern faults prevail everywhere. The exclusion from the total pattern is the western border of the Kazakhstan low hill area where the structural and geomorphological pattern is controlled by the north-south strike Ulytau area of faults. Against the background of the general roof elevation of the Kazakhstan shelf, various differentiated movements took place resulting in fracture of the Mesozoic peneplain and determining the further allocation of heights and the plastic structure of macro- and sometimes mesoforms of the terrain.

The newest tectonic movements divided the crust of earth within the territory of Central Kazakhstan into a battery of morphostructures directly corresponding to large neostructural blocks (Figure 1). Generally, the morphology of the territory terrain has some notable regularities, such as the layering of macroforms and the lithomorphic nature

of the meso- and microforms of the terrain. These conclusions about the regularities of the morphological structure of the explored territory are not only the statement of the information received from literary sources, but also the result of the analysis of 19 near EW and NS trending complex geological and geomorphological profiles built by us using 1:500,000 scale topographic and geologic maps of the territory of Central Kazakhstan, which are rather well confirmed by the above-mentioned regularities. In hypsometrical terms, Central Kazakhstan is distinctively divided into two parts - the western and eastern ones, which are elevated compared to the relatively plain surface with few depressions. Against the background of the denudation plains, the mountain and knoll groups are present (with absolute altitudes over 1,000 m) – the NS oriented Ulytau-Arganatinsk massif in the west and the EW oriented Kokshetau massif in the north. Between these two elevations, the plain of the Teniz depression is located, which is horseshoe-shaped, stretched in the EW direction, and open for the flows of the prevailing (western and northwestern) air streams (Figure 2). This position determines to a known extent the physical properties of the air and relatively lesser gradients and temporal variability of certain meteo indexes (temperature, pressure, humidity), than the eastern slopes of the Ulytau-Arganatinsk mountain group and the plains of the Dhezkazgan-Sarysuysk depression that are more protected from the impact of the main air mass transport. To the east of the Ulytau-Arganatinsk mountain-and-knoll elevation, there is the EW-oriented Sarysu-Teniz water parting – the elevated knoll-and-ridge plain with absolute altitudes of 600-800 m, which transforms into the large Central Kazakhstan low-mountain belt. The core of the belt consists of the system of low mountains lying on the elevated foundation of denudation plains and hummocks. The low-mountain belt of the EW strike along with the Sarysu-Teniz elevation are the main water parting between the Basin of the Arctic Ocean and the Aral-Balkhash internal drainage basin (Figure 1). To the north and the south of the low-mountain belt, there is a layering of altitudes from 1,000 m to 340 m in the south (the denudation coastal plains to the north of the Balkhash lake) and to 250 m in the north (the denudation plains of the near-valley interstream area of the Irtysh river), whereby the northern slopes of the low mountains are steeper than the southern ones, have more springs and vegetation.

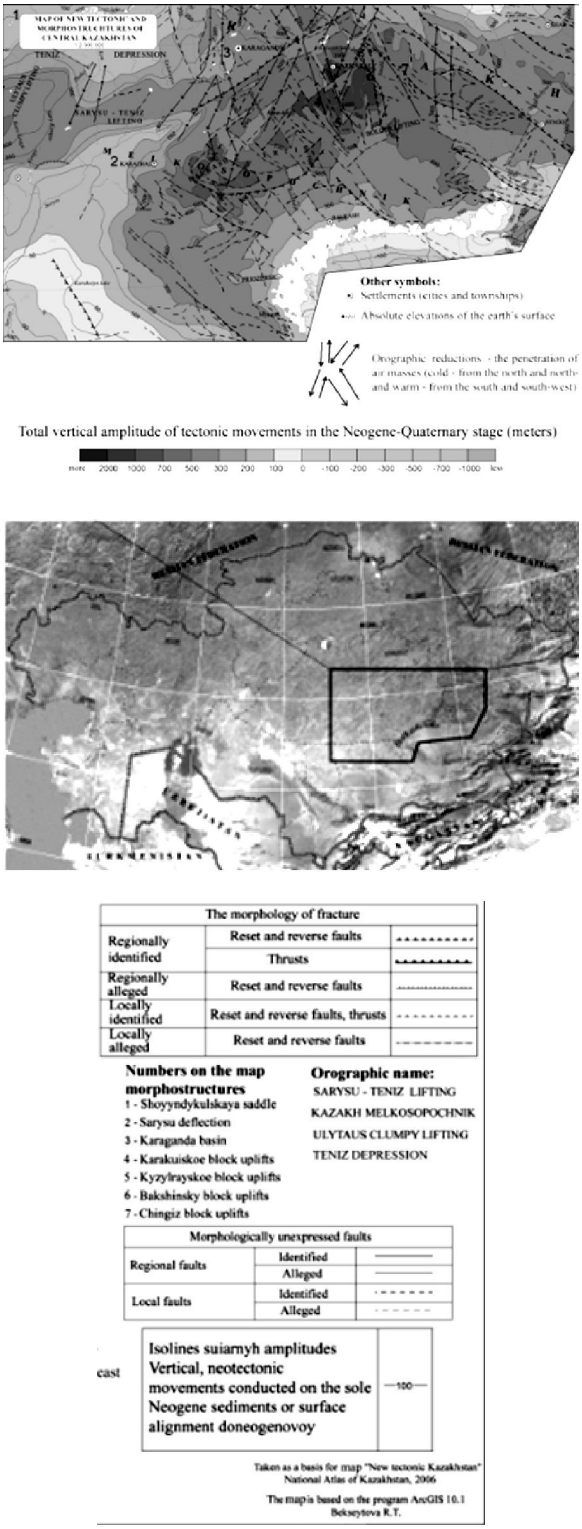



**Figure 1 – Map of the recent tectonics and morpho structures of Central Kazakhstan**

The Ulytau mountain-and-knoll upland and the Central low-mountain belt play the role of a

barrier on the way of the prevailing air streams – the northwestern, southwestern, and northeastern ones, which are distinguished by the heat and humidity contents. The air masses of the northern and western courses, especially the lowest layers transform (become drier) when passing this barrier, and their barogradients increase. The latter circumstance is especially clearly manifested in the relative densification of summer oro-isobars along the southern slopes of the Central low-mountain upland and the eastern and southeastern slopes of the Ulytau upland, which is determined by reinforcement of the air-mass processes and the local anti-cyclonic pattern. During winter, the unstable pattern of higher air pressure prevails across the studied territory, and it is often disturbed by frequent bursts of cold air of the more powerful Asian cyclone from the north and the northwest along the NS oriented intermontane depressions – river valleys. According to regional reports of weather stations (WS) of the Dhezkazgan and Karaganda hydro-meteorological services (1996-2010), the average summer temperatures in the north of the Karaganda region varied between $+19.9^0$ and $+21.4^0$C, and in the south (according to the WS of Kayrakty and Balkhash) and the eastern part of the Dhezkazgan region (according to the WS of Dhezkazgan and Terekta) – between $+25.8^0$ and $+26.7^0$C. The average winter temperatures in the north varied between $-16.8^0$ and $-18.2^0$C and in the south and the east – between $-12.3^0$ and $-13.1^0$ C. The annual rainfall changes in the same direction – from 250-300 mm in the north and the west to 120-150 mm in the south. The scarce snow cover is blown off by strong winter winds to the terrain depressions. The morpho-orographic barrier, while determining the provincial difference of the climate within the considered territory, is rather clearly fixed by the northern margin of the semi desert area (according to the physical and geographic zoning of Kazakhstan made by L.K. Veselova and G.V. Geldyeva; and the internal differences of the morpho-orography of the considered territory – by differentiation of the zonal (dry steppe and semi desert) types of landscapes [12].

The intensity and morphologically expressed fractionality of the manifests of exodynamic processes in the circumstances of the subarid and arid climate of Central Kazakhstan are mainly determined by the orientation of the slopes (from macro- to microslopes) with respect to sunbeams. The slopes of the northern exposures as opposed to the southern ones differ by their greater turfness and milder contours. The exposure of slopes determines the period of complete snowmelt. Snow "pancakes" on the shadowed slopes of the northern exposure are observed in few spots until the end of May, and on the slopes of the southern exposure, they disappear completely by the end of March or the beginning of April. The comparatively quick snowmelt in the form of a continuous stream or smaller streams over the sparsely turfed surface of the elevated slopes of the southern exposure (within 10-20 days) results in formation of small-cell "spoon" network (the depth of small grooves and horns of the stream flows is between few and several dozens of centimeters) and formation of deluvial plumes between 1 and 1.5 m near the bottom of slopes. At the slopes of the southern and eastern exposures and the inner steep ($35^0$ and more) slopes protected from the moisture-laden air, the processes of physical erosion are active, resulting in emergence of the processes of avalanches and sloughing (Figure 3). Near the foot of these slopes, gravel sloughs (cone taluses, plume taluses) flock, resulting in assemblage of stones as large as 1-5 m and larger. Their surface slopes vary between $15^0$ and $30^0$ (Figure 3). At the same time, we need to notice that the avalanched slopes and taluses are often associated with the areas of refreshed and newly-occurred faults and fracture systems, which control the erosion network of the low-mountain and knoll groups of Central Kazakhstan.

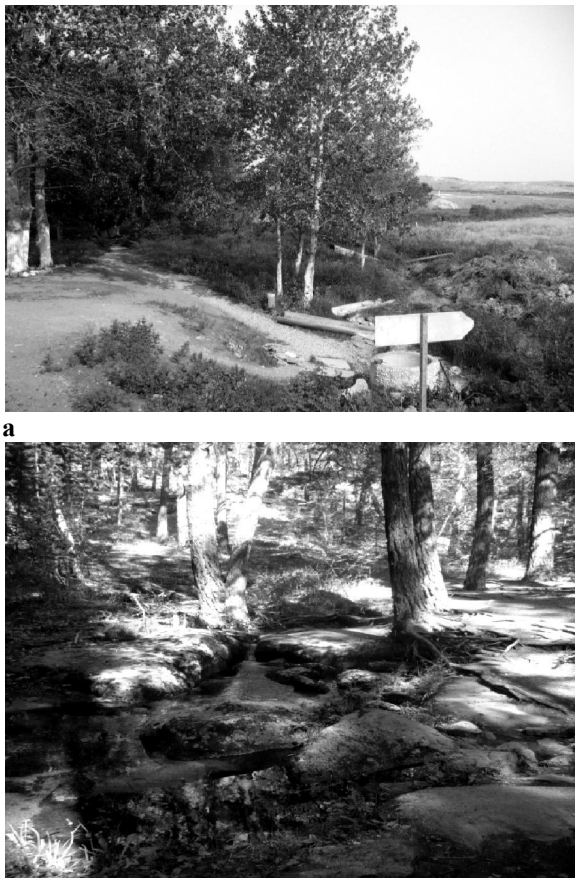
The morpho-orographic and morpho-climatic factors determine the density of the drainage of the territory. It generally decreases from the north to the south and varies heavily depending on the hypsometrical level of the territory. Favorable conditions for formation of a comparatively dense drainage have emerged on the slopes of the Central Kazakhstan low-mountain belt and the Ulytau elevation. The low-mountain and knoll terrain and fracture groundwater decrement at the foot of these massifs contribute to emergence of small river flows and lakes in the depressions of the earth surface (Figure 4).

The increase in the aridity of the climate and, accordingly, the lack of humidity within the relatively leveled inner parts of the considered territory determined by the influence of the Ulytau and Central Kazakhstan low-mountain and knoll elevations (these elevations determine the position of the continental axis of Kazakhstan within the considered territory as determined by E.N. Vilesov, V.N. Uvarov etc.) contribute to the development of wind processes, the formation of the suffosion, sor-deflation and takyr-like basins and development of eolian buildups (within the lower course of the Sarysu River).

Virtually all of the areas of the denudation platform plains are located in the semi desert and desert zone where the processes of natural desertification and degradation of land are reinforced by the impact of the anthropogenic factor – survey and extraction of solid commercial minerals.

**Figure 3 -The eastern and south-eastern slopes of Ulytau low mountains covered with cracks and shattered fragments of boulders and gravel with sand filler (photo R. Bekseitova)**

The man-induced impact caused by extraction of solid commercial minerals and the infrastructure associated with it (construction of residential facilities, reservoirs, canals, power lines, and roads has resulted in increased scavenging of fresh groundwater actively used not only by the industry but also in everyday economic activities) has contributed to changing the terrain environment, activating negative exodynamic processes, degradation and destruction of productive topsoil over large areas (direct impact). The implicit impact of anthropogenic interference is the intensification of deflation, erosion, salinization, and erosional dissection processes. The most characteristic exodynamic process that transforms the morphology of the terrain of the mining-knoll denudation platform structures of Kazakhstan in the circumstances of the arid climate is ***sor-formation***. Development of this process is associated with the capillary outlet of groundwater due to extensive surface vaporization and crystallization of salt extracted by water from the rocks, arrival of salt from the enduring depth of unstratified rock as well as due to reallocation and transport of salt from sedimentary salt-bearing rocks. Salinization of soil with accumulation of easily and moderately dissolved salts is widely manifested in continental basins on lake and river terraces. Evaporative concentration of salts from saline groundwater lying not very deep (less than 2 m) results in formation of salt marshes and puffed soil both in valleys and upland areas, which are exposed to deflation in dry seasons.



**a**

**b**

**Figure 4 – Spring and water course at the foot of the equalized of the Ulytau (a) and Bektau-Ata (b) mountains (photo L. Veselova)**

Chloride-sulfate and gypsum types of salinity with soluble salt content up to 10%, and in saline crusts — up to 60% prevail. In the folded by loam depressions on the surface of aligned steppe water-parting areas (watersheds) of the semi desert zones of the region, solonetzes and takyrs are formed. During the period of snowmelt after rainfalls, the solonetzes and takyrs are saturated with water and become impassable barriers for vehicles. During dry seasons with heavy winds, their surfaces are intensively deflated and flat sor-deflation basins emerge. Such flat oval-stretched patelloid depressions are typical of the Yesim-Seletinsk interstream area, the eastern and northern Balkhash area, and also, they are observed along roadside embankments (Figure 5). The latter is conditioned by the fact that roadside embankments deter the escape of ice and rain waters, thus forcing it to accumulate with furthervaporization, extracting in-depth mineralized water.

**a**

**b**

**Figure 5 –Road sides a line (a -in the initial stage, b - in the final stage) (photo R. Bekseitova)**

During recent years, the decrease in the level of ground- and underground water caused by intensive economic land development has resulted in deflation of the puffed salt-bearing layer and active formation of kettles and depressions. Perennial field observations and interrogation of local residents (over 80% of the responders) showed that the area of the negative forms of such origin has been increasing.

**Summary**

Thus, the study of the whole battery of materials related to the subject of the research gives reasons to come to the following conclusions:

1. while controlling the natural climatic conditions of the territory of Central Kazakhstan, the morpho-orographic factor also conditions the whole set of exodynamic processes – the temperature and salt eolation, surface wash of rain, deflation, erosion, sor-formation, karst, etc. – the nature and the intensity of their spatial display;
2. the strong impact of the morpho-orographic and morpho-climatic factors, especially in the inner parts of the considered territory, is conditioned by the anthropogenic factor. The natural turfness of the surface limits the deflation; but the buildup of the anthropogenic load per unit of square results in rapid activation of the water and wind erosion and extension of the land exposed to active surface wash of rain, takyr- and sor-formation, deflation, and other processes;
3. The intensive development of solid commercial minerals accompanied by establishment of respective infrastructure and increase in population of industrial centers has resulted in intensive development of both surface water and particularly groundwater. This development in the circumstances of the arid climate and the growth of loam and clay deposits has resulted in the level change of ground and underground water and in development of a battery of unfavorable exodynamic processes, including extensive sor-formation and sor-deflation.

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