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The Role of the Tenir-Too Relief Steps in the Formation of High-Altitude Belts

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Abstract

The article discusses regularity of the formation of high-altitude zones on the mountain territories of Tenir-Too and their relationship with geomorphological complexes and the relief steps. The main purpose was to classify geomorphological complexes and to concretize their morphological characteristics. The belt structure consisting of two mixed rows is analyzed. Excess, elevated, medium-moistened, semi-moistened, semi-arid, and arid types of altitudinal belts were proposed.

Keywords

Tenir-Too, Geomorphological Complexes, Mountain Complexes, Step, Reliefs, Accumulative Relief

1. Introduction

Tenir-Too is one of the large mountainous territories of Central Asia, distinguished by a particular location of mountain systems and a set of altitudinal belts. Tenir-Too is geologically older than the rest of the arid mountains of Eurasia, which is characterized by peculiar geographic patterns, which, during development and degradation, has its inherent features, relief forms, a landmark of mountain structures and valleys [1]. Tibet, Himalaya, Pamir, Tien Shan, and Altai mountains comprise Highland Asia and constitute the most glaciated kinds [2].

The mountainous region is surrounded by flat areas that have a desert character and determine the appearance of landscapes and altitudinal zones. In some regions, Tenir-Too is located in the vicinity of deserts, in others with highly dissected high mountain ranges. The first ones include the Chatkal-Talas and

Chui-Kemin sectors, bordering on Kyzyl-Kum, Betbak-Dala, and the Kazakh steppes. The second can be attributed to the eastern part of Tenir-Too, bordering on the high mountain ranges of Kakshal-Too and Terek-Too, in the east of which the continental inner deserts Takla-Makan (Tarim, Kashkaria) are located, the influence on the Central and Inner Tenir-Too are hardly noticeable.

Several works about sedimentation in foreland basins, the rise in the base level for mountain belts erosion were described [3]. Several studies performed on the impact of climate change in Central Eurasia from tree ring-based record information [4].

Altitude level, *i.e.* the layering of the relief is the most significant feature of the morphology of mountains experiencing orogenic uplift [5] [6] [7] [8] and is perceived as geomorphological zoning, or zonality [6]. In the center of which there is a worn-out mid-mountain relief inherited from the past, raised in the process of orogenesis to the height of the dome-vault (Inner Tenir-Too) [9]. Around this core is a dismembered alpine relief. On the outskirts of the mountain structure, there are foothill zones, and behind them, the accumulation and subsidence zone are foothill plains, the age of which is significantly different from each other. The upper stage of the mountains is of Oligocene age, the middle stage of the Oligocene-Neogene is lower than Quaternary; the lower stage of the middle Quaternary is modern, *i.e.* the higher the tier, the older it is [10].

The Pamir-Alai mountains represented in **Figure 1** [11], identified four layers of relief: the upper denudation, the ridge part of the mountains, expressed everywhere in the Tenir-Too mountains; upper accumulative near-ridge, the surface

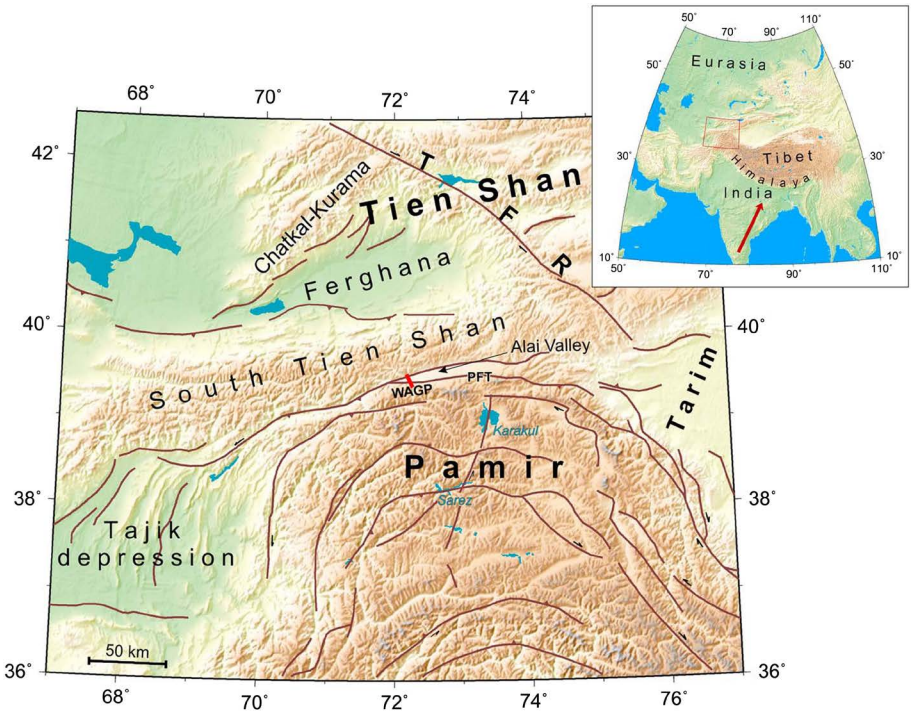

Figure 1. Topographic map of the Pamir and Southwest Tien Shan located at the northwestern end of the India-Asia collisionalbelt (inset) [11].

of accumulation of products of destruction of the previous relief (Inner Tenir-Too) [8]; lower denudation of the slope of the mountains, the "zone" of erosional dissection and denudation is expressed on the wings of the lateral ridges; the lower accumulative modern: floodplains, terraces, talus, adyrs, foothill plains everywhere along the periphery of mountain uplifts. **Figure 1** is showing the Pamir and Southwest Tien Shan mountains location that is not divided into sections, and the inset is showing divisions into 1) sectors on the flat surfaces; 2) sectors on the slopes and sub hills; and 3) sectors on the mountain ridges. Air masses are influenced according to the sector divisions based on the seasons. When determining the geomorphological complexes of the Tenir-Too mountains, we used the layering system of relief [8].

2. Geomorphological Complexes

This is a part of the earth's surface that differs from other regions by identical geological and historical development, tectonic structure, and relief character. The main geomorphological complexes of mountainous territories are mountains of different altitude levels (highlands, midlands, and lowlands), foothill plains, foothill valleys, and wide plains. Adyrs (high, medium-altitude, low-altitude) are parts of the foothill complex of mountainous areas. The Tenir-Too territory consists of 8 relief levels, differing in the shapes of irregularities and the height of the levels of the landscape belts, where the height of the relief level is the basis of the altitude of the landscape belts and their ranges.

2.1. Mountain Complexes

Tenir-Too consists of four levels (2500 - 3000, 3000 - 3500, 3500 - 4000, and over 4000 m), which are divided into low, medium, high, and highest mountains. The highest mountains include the ridged parts of the Chon-Alai and Kakshaal-Too mountain systems, the height of which exceeds 6000 m above sea level. The main relief-forming factors are exogenous processes under the influence of the glacial-nival and stony-tundra landscape. Alpine complexes covered mainly by rocks of the Paleozoic, partly Meso-Cenozoic periods, the surface of which consists of erosion-dissected reliefs, numerous Karr fields, ancient and modern moraines, and trough-like valleys. The total area of the Tenir-Too mountain complexes is 84.7 thousand km^2 (30.8% of the total area) and consists of three (high mountain, mid mountain, and low mountain) steps [12].

2.2. Alpine Step

The alpine step of the mountains consists of four stages. The upper denudation the ridge part of the mountains expressed in the mountains with an average height of more than 4500 m above sea level. These include the Ashuu-Tor ridge (5000 m), Kan-Too-Hantengri (6000 m), Meridian (5000 m), Enilchek-Too (5100 m), Boz-Kyr (4900 m), Kakshaal (4500 m), Kulγ (4600 m), May-Bash (4900 m), Sary-Jaz (4700 m), Borkoldoy-Too (4500 m), Kok-Kyya (4500 m),

Torugart (4500 m), etc. The high-mountain stage consists of the following parts of the mountains: the upper denudation part, the upper accumulative part the ridge part, the lower denudation part the slope part, and the lower accumulative part the modern parts of the mountains. The high-altitude step is a territory of landslides and taluses. The upper denudation-ridgeline part of the mountains is distinguished by a strong gravitational process and widespread rock falls landslides and relief debris. The upper denudation layer of the relief is absent in the Kyrgyz Ala-Too (3700 m), Trans-Ili Ala-Too (3700 m), Talas Ala-Too (3900 m), Borkoldy (4500 m), Moldo-Too (3600 m), etc. represented by individual peaks, but is widely expressed in the Baibiche mountains (3900 m), Borkoldy (3700 m), Kalba-Too (3700 m), Koshoi-Too (3100 m), Fergana (3600 m), Suusamyr (3500 m), etc. It is very weakly expressed in the At mountains Oinok, Kakshaal, Meridianalny (5000 m), Kan-Too (6000 m), Koikap (4000 m), etc. The upper denudation stage is an area of destruction, avalanches, and taluses.

Landfalls occur when rock masses destroyed by weathering or tectonic processes not retained on steep slopes and fall under the influence of gravity. The landslides are typical for the high mountains of the glacial-nival and partially alpine belts of the Tenir-Too Mountains. This is due to the leading role in the denudation of physical weathering and its intensive development where the glacial-nival cover is more powerful and chemical weathering is active. The volume of one collapse can be 50 - 100 m^3, and up to 500 m^3 found [13]. Usually, large landslides, moraines, and small lakes are located at high absolute heights, at the end of the glaciers they are insignificant in size (no more than 100 - 200 m^2), located in a chain or small groups. Rock falls, moraines and shallow lakes are ubiquitous in all Tenir-Too mountains.

Analysis of maps of materials and field studies show that the area of formation of glacial-nival belts is the denudation ridge part of the mountains, where 8208 glaciers are concentrated with a total area of 8094.5 km^2 (across Kyrgyzstan). Glaciers are located at different heights and in some mountains have a belt character (Kakshaal, Teskey Ala-Too, Kungey Ala-Too, Ili, and Kyrgyz Ala-Too, etc.), in many mountains (Chatkal, Fergana, Atbashy, etc.) as shown in **Figure 2** marked with circle [14].

Observations and measurements of the intensity of frost weathering of rocks carried out by the Institute of the Earth's Crust on 47 specially laid out areas in the Eastern Sayan Mountains from 1969 to 1974 showed that every year 1.5 to 3 kg of clastic material comes from 1 m^2 of rocky slopes, *i.e.* annually from 1 km^2 of the surface of the rocky slope more than 1200 m^3 of destroyed rocks are supplied. Its formation is due to the action of repeated freezing of water, which penetrates macrocracks in mineral grains. Another factor in the formation of clastic material in the glacial-nival zone is biochemical weathering. The rocky surfaces open to snow and the ridgeline part of the ridges characterized by alpine "tan". As a result, fine earth formed, consisting of small crushed rocks on which a tundra type of landscape formed, *i.e.* loach tundra. Goltsevaya tundra has a fragmentary distribution only in the Akshyirak, Meridionalny, Sary-Zhaz, Koolu,

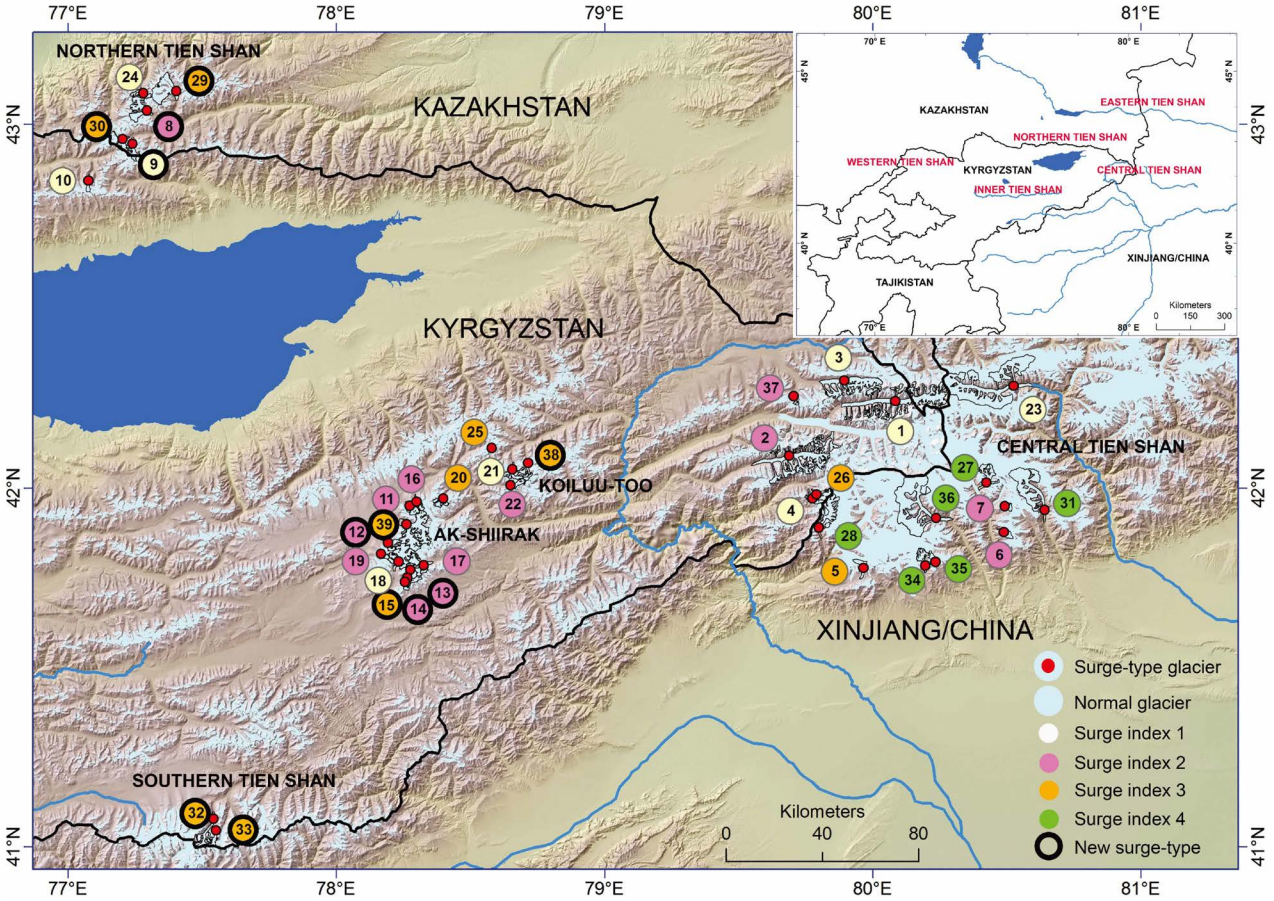

Figure 2. The location of the 8208 glaciers with area of 8094.5 km² in the Tien Shan mountain.

Ak-sai, and Engilchek mountains. As a result of exogenous destruction in the crest of the high mountains, glacial-nival and goltsovo-tundra landscapes were formed. The glacial-nival landscape is the main altitudinal belt, and the goltsovo-tundra landscape is isolated closed belts, *i.e.* transitional areas between alpine and glacial-nival belts.

2.3. Mid-Mountain Stage

The mid-mountain stage covers the mountains located at an altitude of 3100 - 3500 m above sea level. These include the mountains Kalba-Too (3400 m), Kemin (3100 m), Kuru-Ayryk (3500 m), Kyzyl-Bulak (3000 m), Ok-Torkoy (3500 m), Ala-Myshyk (3200 m), Akshyirak (3400 m), Achy-Tash (3600 m), Bauk (3000 m), Kabyk - Too (3400 m), Kapka - Tash (3500 m), Kara-Zhorgo (3600 m), Karacha-Too (3100 m) other. (100 - 10 thousand years) under the cover of glaciers [5] [7] [15] [16] [17] [18]. As a result, about 30% of friable materials are confined to the foothill parts of the valleys in the form of cones of talus and landslides. Around this core, the wings dismembered relief of the alpine appearance in North and South Tenir-Too.

In general, the mid-mountain stage of the Tenir-Too mountain systems consists of the upper accumulative the crestal part of the mountains, the surface of

which is covered with the accumulation of products of destruction of the previous layer of the relief. These include the denudation-slope part of the mountains, "zones" of erosional dissection and denudation, fragmentarily covered with coarse detrital rocks from the overlying zones, where on many slopes it has a talus-slope character, formed by the movement and deposition of loose material of rocks.

A prerequisite for the formation of a talus-slope landscape is the presence of a steep upper slope. The harsh climate of the Central and Inner Tenir-Too leads to the intensive destruction of rocks, which serve as material for talus bodies. In some places, they completely encircle the foothills of the mountain slopes, which are distributed on the surface of the relief (Karacha-Too, Ukok, Kabak, etc.) or confined to separate hollows and often cover the slopes almost to the crest of the mountains. On the outskirts of a mid-mountain structure, there is a zone of foothills and behind it a zone of accumulation and subsidence foothill plains, intermontane basins. The modern bottom of intermontane basins, valleys, terraces, adyrs, and river floodplains is a zone of accumulation of rocks of the overlying relief layers. The prerequisites for their formation are the small steepness of the territory, *i.e.* denudation layers of mountains zones of washout, soil destruction; accumulative layer zones of accumulation of sediments and salts, which play an important role in the formation of high-altitude belts of landscapes of the Tenir-Too mountains.

2.4. Low-Mountain Stage

The low-mountain stage of mountains consists of many mountains with a height of 1500 - 3000 m above sea level. The total area of the low-mountain steps of the mountains is 919.0 thousand km^2, that is, 46% of the mountainous areas of Tenir-Too. These include the mountains Arpa-Tektir (2800 m), Karagatty (2300 m), Kara-Zhylga (2100 m), Taktek (2700 m), Kyzyl-Ompol (2900 m), Shumkar-Too (2500 m), Kara-Koo-Zhumat (2700 m), Karacha-Too (3100 m), Kurama-Too (2700 m), etc. Almost 90% of the mountains are located in the latitudinal and close latitudinal direction. Accordingly, moist air masses coming from the west and cold air masses coming from the east of the "Cold Pole" of Central Tenir-Too equally affect both slopes of the mountains (northern, southern). As a result, the sides of the mountain valleys (Zhumgal, Chaek, Orto Naryn, etc.) receive the same amount of precipitation and temperature indicators. Therefore, the landscapes of the intermontane valleys are practically the same and occupy a large space, forming continuous belts, and the fragmentary arrangement is almost absent (Kokomeren, Minkush, Kara-Kuzhur, Kochkor, etc.).

As a result of the same climatic regime within the low-mountain steps of the mountains and along the sides of the valleys, multifaceted processes of cryophilization and xerophytization of plants occur [10] [19]. Xerophytization and cryophilization of plants assessed in two ways: as the ability of plants to endure prolonged and deep dehydration [9] and as the ability to economically use water with its increased supply by root systems [20].

The first assessment is based on the recognition of passive adaptation to drought, the second is very active [19]. Passive adaptation appears to be florogenetically unfertile, while active adaptation to drought leads to intense morphogenesis. Thus, continuous and small areas of xerophytic and cryophilic groups of landscapes are formed as a result of the adaptation of plants to the cold or hot climatic conditions of mountains and mountain valleys.

The low-mountain step, depending on the morphological differences caused by the lithology of the rocks, the degree of dissection of the relief, and the nature of the vegetation cover, is divided into several types of relief: a zone of low-mountains with intense dissection (the highest amplitudes of relative heights of 1000 - 2000 m); low mountain with fractional sharp dissection (amplitudes of relative heights 1000 - 1200 m); low mountainous with soft contours (800 - 1000 m) and flat surface adyr zones (500 - 800 m). The step of low mountains with intensive dissection is areas of strong destruction of rocks, where the boundary of the steps is defined relatively clearly as a line in which the mid-mountain complex ends and in the lower part as a line where adyr strips and sloping plains begin. The upper boundary is vague since in many places the transition of a weakly dissected middle-mountainous relief to a low-mountain one occurs gradually and is almost invisible. The absolute heights of the border of the low-mountain complex in different regions of Tenir-Too vary greatly and are in the range from 800 m to 2000 m. For example, the height of the low-mountain step in the Kemin valley is 1800 - 2000 m, in Ketmen-Tyube 1600 - 2100 m, in Kokomeren 1000 - 2000 m, in Orto Naryn 1000 - 1600 m, in Talas 900 - 1700 m, in the Chuy valley (southern side of the valley) 800 - 1000 m. The boundaries of the low-mountain complex are invisible in Ak-Sai, Arpa, Sary-Jaz, Koolu, Engilchek, and in the syrts of the Issyk-Kul valley, because these regions are located at an altitude of 2600 (Arpa) to 3500 - 3600 m above sea level.

2.5. The Lower Accumulative Complex

The lower accumulative is a modern complex of the Tenir-Too relief type, both on the outskirts and its inner ridges consists of three genetically separate relief subgroups: areas of ancient accumulation, denudation, and newest accumulation. These include the Chui, Issyk-Kul, Kochkor, Dzhumgal, Ketmen-Tyubinsk, Chatkal, Talas, Kemin, and other valleys. The difference in the appearance of the types of relief in each of these valleys is due to the structure, the degree of dissection, and the nature of the surface deposits. The lower boundary of this complex of relief types is relatively distinctly defined as the line where the slopes of the mountains or foothill sloping plains end. For example, on Issyk-Kul, the line passes through the shores of the lake, and in the valleys of Chui, Talas, Chatkal, Ketmen-Tyube, Suusamyr, Dzhumgal, and others through the river floodplains. The upper border is often not distinct, since in many places the transition of a weakly dissected mountainous relief to a foothill one occurs gradually, almost imperceptibly (Ak-Sai, Arpa, Sary-Jaz, Suusamyr, Kochkor, etc.).

The absolute height of the boundaries of the foothill complex of the relief type in different parts and valleys of Tenir-Too is different: the lower border runs at 1000 - 1600 m, and the upper one is 1100 - 2100 m. The lower accumulative complex is an area of flooding of temporary water flows and mudflows. The landscapes of the complex are changeable in time and locally in space, since the denudation layers of the relief are zones of erosion, soil destruction, and accumulative layers are zones of accumulation of sediments and salts. The higher-lying layer is colder and older than the lower-lying layer, which led to different species composition of the vegetation cover, and the dissimilarity of some vegetation belts and relief steps to each other. This is how the steppe belt joins with the youngest and warmest lower accumulative layer of the relief; semi-desert and desert landscapes merge with areas of accumulation of small rubble particles of rocks carried away from the overlying zones by mudflows; the forest-steppe and forest landscape merges with the middle accumulative layer of the relief, which has a dilapidated and semi-concave character.

A common characteristic feature of the complex is the predominance of the steppe, dry steppe, semi-desert, and rarely desert landscapes with stony-gravel gray soils and slightly sodded soils [21]. In many areas, destroyed rocks occupy relatively small areas, which determine the fragmented distribution of forest landscapes. The difficulty in establishing such a closure lies in the fact that in different regions of Tenir-Too, some tiers are clearly expressed, others are hardly noticeable, and others may be completely absent. So, in Kakshaal (4500 m), in Enilchek (4400 m), Sary-Jaz (4700 m), Koolu (4600 m), Koikap (4000 m), Akshyirak (4700 m), etc. the border of altitudinal zones is invisible.

3. Conclusion

The layering of the relief of the mountains creates types of habitats in which certain types and types of vegetation adapt, forming xerophytic, mesophytic, and hydrophytic groups of plants. Steppe and dry-steppe landscapes are formed from xerophytic groups of plants on arid slopes (southern and eastern), meadow and forest landscapes on humid mountain slopes (western and northern), and on semi-arid and semi-humid slopes (southwestern, southeastern, and mountain slopes) meadow-steppe and forest-steppe landscapes, and in the crest of some mountains north-wet glacial-nival and tundra types of landscapes are formed.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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