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Digital Spectra and Analysis of Altitudinal Belts in Tianshan Mountains, China

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Abstract: Based on the framework of the geo-info spectra of montane altitudinal belts, this paper firstly reviews six classification systems for the spectra of mountain altitudinal belts in China and considers that detailed regional study of altitudinal belts is the key for reaching standardization and systemization of mountain altitudinal belts. Only can this further identify and resolve problems with the study of altitudinal belts. The factors forming the spectra of altitudinal belts are analyzed in the Tianshan Mountains of China, and a digital altitudinal belt system is constructed for the northern flank, southern flank, the heartland, and Ili valley in the west. The characteristics of each belt are revealed with a summarization of the pattern of areal differentiation of altitudinal belts.

Keywords: Tianshan Mountains; altitudinal belt; digital spectrum

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1 Brief Review on the Classification Systems for the Spectra of Mountain Altitudinal Belts in China

With about 70% of its land area as mountains/ plateaus, China is the most extensive mountain country. From south to north, it covers almost all of the temperature zones of the world; from east to west, many landscapes, including humid forest, semi-arid grassland and arid desert, succeed one another. Especially in the southwest China loftily towers the most immense and young plateau on the earth - the Tibet Plateau, on which develops landscapes endemic to China, such as alpine steppe and alpine desert. Since the 1960s, Chinese botanists, pedologists and physio-geographers have, based on their own knowledge, investigated and generalized the spectrum system of altitudinal belts in mountains of China, and left us with rich data. The classification systems involving altitudinal belts of the whole country mainly include:

1.1 System of altitudinal belts based on vegetation regions

A paper entitled "Characteristics of mountain vegetation altitudinal belts in vegetation regions of China" (Hou 1963) is the first to generalize the pattern of mountain vegetation belts in China (Zhang 1994). It divided China into eight vegetation regions, each region including several vegetation zones. A representative spectrum of altitudinal belts was listed for each vegetation zone, including the distribution height of each belt. But some zones lacked representative spectra, e.g., the Tibetan alpine steppe zone and the Tibetan alpine desert zone. Later on, the vegetation division scheme and vegetation zone classification were changed.

1.2 System of altitudinal belts based on soil zones

Ma Rongzhi (1965) identified 18 mountain soil zones and 30 spectra of mountain soil altitudinal belts without the elevations of altitudinal belts. He also divided plateau into four types: alpine plateau, Yunnan-Guizhou mountain plateau, the Loess hill plateau, and northwest Inner Mongolian inland plateau.

1.3 System of altitudinal belts based on vegetation zones

Liu Huaxun (1981) provided 1~3 exemplary spectra of altitudinal vegetation belts for each of the 14 vegetation zones distinguished in *Vegetation Regionalization* (1960) and *Vegetation of China* (1980). The latitudinal and longitudinal patterns of altitudinal belts were also discussed. He especially emphasized a "zonal principle" of the structure of vegetation belts, namely, the dependence of altitudinal zonation on horizontal zonation.

1.4 System of altitudinal belts based on eco-geographic types

Zhang Xinshi (1994) generalized seven eco-geographic types of altitudinal belts in terms of seven vegetation realms of China: frigid temperate-tundra type, temperate deciduous/ broad-leaved forest sub-alpine meadow type, East Asia subtropical evergreen broad-leaved forest-alpine meadow type, northern tropical montane rainforest and seasonal forest type, temperate steppe type, temperate desert and extreme-desert type, and the Tibet Plateau type. Five macro profiles were used to illustrate the spatial succession and basic pattern of the altitudinal vegetation belts in China. The sub-alpine belt was treated as the lower part of the alpine belt, and was given a clear definition: the transition from montane forest belt to alpine vegetation belt, characterized by various species of shrub, meadow or steppe, and coppice communities. The question about the position of the sub-alpine belt in the vertical spectrum of altitudinal belts, which has puzzled botanists and geographers for a very long time, is thus clearly resolved.

1.5 System of altitudinal belts based on structure types

Peng Buzuo and Chen Fou (1999) made another generalization of altitudinal belts in China. Two series of altitudinal belts were firstly put forward: the monsoon and the continental, which contain seven structure type groups (humid, sub-humid, alpine sub-humid, semi-arid, arid, alpine semi-arid, alpine arid). A total of 18 structure types were distinguished.

1.6 System of altitudinal belts based on digital spectrum

Recently, a conception of "digital spectrum of altitudinal belts" was put forward (Zhang B. 2002, 2003), including relevant methodology. By constructing a special data structure for montane altitudinal belts, altitudinal belt data and graphs were digitally and dynamically associated. All of the altitudinal belts everywhere can be put in one structured table, and the graph required can be created instantaneously. In addition, a standard definition for altitudinal belts was outlined, and a hierarchy of spectra of altitudinal belts was constructed. The physical zone, a basic unit in the scheme of Comprehensive Physical Regionalization of China (Huang B. 1959), was defined as the base belt of the spectrum of altitudinal belts. A three-level system of digital spectra of altitudinal belts was proposed, including 31 basic spectrum series and several peculiar spectrum series. Five eco-types and seven spatial models of spectra of altitudinal belts were identified. As a result, the study on China's mountain altitudinal belts has been greatly furthered to a new level.

Regional classification of mountain altitudinal belts have been also carried out, e.g., for Xinjiang (Li and Zhang 1966), western Sichuan and northern Yunnan (Jiang 1964, Zheng and Gao

1984), temperate mountains of the Eurasia (Huang 1962), Henan (Zhang and Zhang 1963), the Tibet Plateau and surrounding mountains (Jiang 1994, Zheng 1994, Zhang 1995), and the Tianshan Mountains (CASMIT 1985). Regional study of mountain altitudinal belts can be divided into two types: based on vegetation regions and based on spectrum structures or climate types, with normally a 2 ~ 3 level hierarchy.

In short, about 50-year nation-wide study of mountain altitudinal belts started generally from vegetation study, some from soil and some from a comprehensive perspective. They all made great progress in revealing the spatial patterns of mountain altitudinal belts. However, it can be easily found that there are obvious different criteria and extents in determining altitudinal belts, and even chaos exists. This hampers the establishment of a national standard system for mountain altitudinal belts.

The concept of digital spectra of altitudinal belts and the exploration of the standard system of altitudinal belts provide a preliminary frame and a basis for the final formation of national info-spectra of mountain altitudinal belts. In the past, a mountain was represented by only one spectrum of altitudinal belts. This is too sketchy and is far from the requirement of establishing the geo-info spectra of mountain altitudinal belts. There is no doubt that detailed regional study of digital mountain altitudinal belts could fill this gap between altitudinal belts and mountain geo-info spectrum of altitudinal belts. Only can this further reveal and resolve problems with the study of altitudinal belts, and gradually reach a scientific and systematic scheme of altitudinal belts in China, or the epitomization of mountain altitudinal belts. This paper is tended to make such an effort.

2 Factors Forming the Altitudinal Belts in Tianshan Mountains

2.1 Elevation

The Tianshan is one of the most gigantic mountain ranges in the world. Only in the territory of China, it extends from east to west for about 1800 km (Fig.1). The relative height of the Tianshan is normally more than 4000 m, and the conditions of temperature and moisture change greatly with height, giving rise to a striking vertical climatic zonation, including, from bottom, (warm) temperate, frigid temperate, frigid, and extremely high mountain nival belts (Zhou 1995, Zhou *et al.* 1998). This is the first factor creating altitudinal landscape belts. Accordingly, from bottom upwards, there develop desert, montane steppe, montane forest/steppe, alpine meadow, and alpine sub-nival and nival belts.

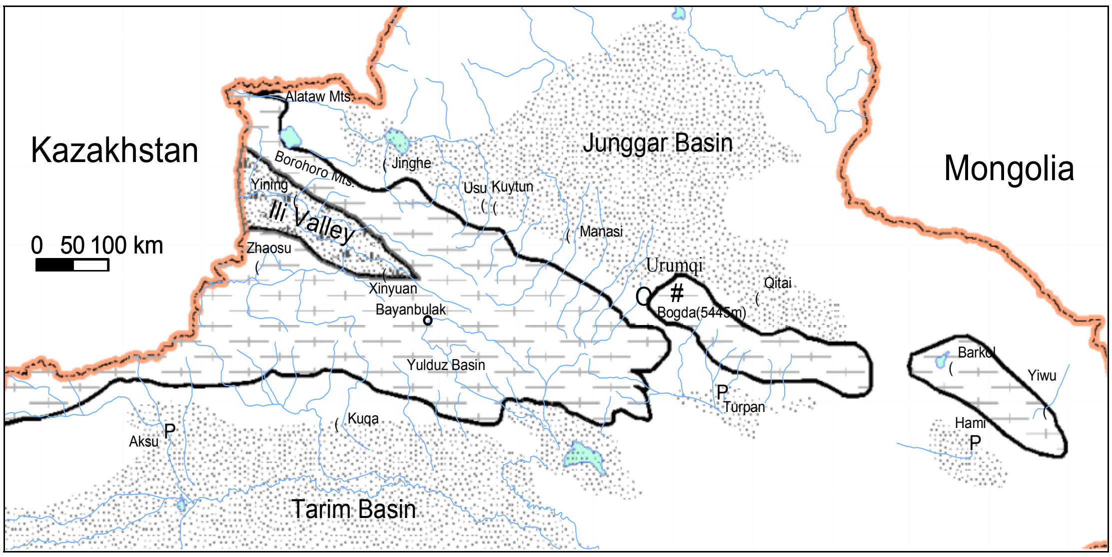

Fig. 1 A sketch map of the Tianshan Mountains in China

2.2 Mountain trend and the prevailing wind

In arid regions, mountain environment are heavily dependent on where the prevailing wind comes and goes. Furthermore, the whole vertical spectrum and areal differentiation of landscapes are also affected to a great extent by the prevailing wind. For example, the northern flank of the Tianshan range receives air masses from the Arctic Ocean, and has a relatively high precipitation in the middle mountains, as high as 400 ~ 500 mm. Facing the extremely arid Taklimakan Desert - the second largest shifting sand desert in the world, the southern flank is a place where air masses subside almost all year round, giving rise to an extremely dry climate. Even in the middle mountains, the rainfall is only less than 200 mm. This severely limits the development of montane forests.

The Ili valley in the western end of the Tianshan range is characterized by a westward outlet, which facilitates the entrance of moisture - laden air masses from the Caspian Sea and the Barkash warm airflow and induces relatively high precipitation (Zhang and Xia 1995). Especially during the process of moving eastward, the moisture-laden air masses are uplifted and topographic rainfall is formed. As a result, the annual mean rainfall reaches as high as 800 ~ 1000 mm in the middle and high mountains, which makes Ili Valley the moistest region in the East Tianshan range. This is shown in the widespread distribution of montane forests and their lower limit at about 1100 m, about 500 m lower than in the northern flank.

Northward, however, just cross the mountain range, a very arid region is formed between the Alataw and Borohoro Mountains, thanks to the foehn effect induced by the Alataw when the western moist air currents get over the Alataw. This rain shadow region has a very dry climate. The altitudinal belts move upward conspicuously. For example, the desert belt can reach an elevation of 1700 m, and the low limit of montane forest goes up to 2100 m. Generally, the montane steppe and forest belts are 500 m higher than that of other areas in the northern flank.

The aridness in the eastern section of the Tianshan Mountains is due to its long distance from the oceans and the almost exhausted effect of western oceanic air masses. In addition, the relatively low altitudes of mountains in this section of Tianshan range are against creating topographic rain. In the Yiwu Mountains, the desert belt climbs up to 2000 m, nearly at the same height as in the southern flank.

As a result, such a macro spatial pattern of climate comes into being in the Tianshan range: the climate is relatively humid in Ili Valley in the west; for both northern and southern flanks, it is comparatively humid in the middle sections and arid in the western and eastern sections. This climatic pattern affects the altitudes and vertical range of all altitudinal belts in the study region.

2.3 Inversion layer and “cold lake” effect

The northern flank of Tianshan Mountains is located in the southern edge of Junggar Basin. In winter, the cold air masses move down the slopes, cooling the surface ground radically. Consequently, the bottom of the basin becomes colder than the slopes - the so-called “cold lake effect.” In other words, there exists an obvious winter inversion layer in the northern flank from 500 m to 2400 m, and the warm layer is at an elevation of 1500 ~ 2800 m (Zhou 1995). Coincidently, montane forests appear at these elevations in northern Tianshan Mountains. Here the monthly average temperature of the coldest month is –12℃. Montane forests can successfully survive the cold winter in the mountains. Meanwhile, rainfall is the richest at these elevations.

The Grand Yulduz Basin in the heartland of Tianshan Mountains is also a “cold lake” in winter. There is also an inversion layer in the surrounding high mountains. Some sunny slopes, if surrounded by mountains on three sides, can serve as “winter house” to herdsmen and their livestock. This facilitates the utilization of alpine meadow in winter. Yulduz Basin is much colder than the southern and northern flanks. The annual coldest month temperature at Bayanbulak town (2485.9 m) is –26.0 ℃, while it is –15 ℃ at Tuoyun (3506.6 m) in the southern flank. Owing to very low temperature in winter and arid environment (annual rainfall 276.2 mm), this basin lacks the conditions for forest growth, even at a relatively low altitude (2400 m) and high temperature (10.4 ℃) in the warmest month.

2.4 Slope trend, micro-landform and surface materials

As is known, different slopes in arid regions receive quite different intensity of solar radiation and show considerable difference in temperature. Generally, it can be 3 ~ 6 ℃ higher in sunny slopes than in shady slopes. With the same amount of precipitation, the different slopes necessarily get different humidity, even to such an extent that different types of vegetation develop on different slopes at the same altitude. This is especially the case in the transitional areas of altitudinal belts. For example, in the transitional area from desert to montane steppe, desert appears on the sunny slope and steppe on the shady; in the transitional areas from montane steppe to montane forests, steppe occurs on sunny slope and forests on shady (Li 1988). In Barkol, the hydro-thermal coefficient is as high as 58.78 in sunny slopes, with the development of montane steppe; in shady slope it is only 37, with desert as the main landscape. In the Tianchi areas, the coefficient is 356 in shady slope and the landscape is forest; in sunny slope, it is only 236 and montane steppe develops (Li 1988). In short, there exists a “two element” structure landscape in the transitional belts in arid mountain regions.

The effect of micro-landform on local landscape is also striking. In the transitional zone of montane forest and alpine meadow or in the middle and upper parts of the forest belt, alpine meadow develops in the lower parts of gentle slopes or on the top of mountains. An explanation is that the micro-landform brings about change to the ground water table, namely water table is shallow in lower parts of slopes; this may promote meadow development. As for the meadow on the top of mountains, strong wind is the main factor limiting forest development. One of the results is the vertical extension of alpine meadow belt. This often raises difficulties to the determination of the limits of altitudinal belts.

The properties of soil on slopes also affect the development of altitudinal belts to a varying degree. On the severely eroded and rocky slopes, xero-mesophitic shrubs and lithophitic cushion plants are well developed. They take over the vertically zonal steppe and meadow normally developing on slopes with fine soil. As a result, the distribution of desert and desert-steppe is extended upwards. This shows most conspicuously in the southern flank that the high distribution of arid altitudinal belts is not only due to arid climate but also to coarse surface materials.

3 Digital Spectra of Altitudinal Belts in Tianshan Mountains

Delimitation of altitudinal belts in Tianshan Mountains involves the basic issue of delimiting vertical belts in mountains of arid regions, for the Tianshan range is a typical gigantic mountain range in arid region. But the criterion for such delimitation has not been agreed on. Fortunately, recent studies on the geo-info spectra of montane altitudinal belts provide a significant framework for such work (Zhang 2002, Zhang 2003). This paper is intended to supply a classification system of altitudinal belts as perfect as possible for the study region.

3.1 Base belts

The base belt of a spectrum of altitudinal belts is the most basic factor influencing the structural properties of the spectrum and its position in the classification system. Its determination is thus the first step to construct the system of altitudinal belts. The Tianshan range extends eastwards for about 1800 km in the territory of China, clearly dividing Xinjiang into two parts, the southern warm temperate zone and the northern moderate temperate zone. Accordingly, the northern flank is located in the temperate-desert grey-brown desert soil zone, which is just the base belt of the spectra of mountain altitudinal belts in northern Xinjiang. The southern flank is situated in the warm temperate-desert brown desert soil zone, which is just the base belt of spectra of mountain altitudinal belts in southern Xinjiang. They are two basic physical zones and serve as base belts. In addition, the Ili Valley in the west of the study region falls in the temperate desert-steppe grey calcic soil zone, although its area is relatively small. And in the heartland of the Tianshan Mts. there are intra-montane basins - the Yulduz basins, where alpine steppe is the representative vegetation upon which a special spectrum of altitudinal belts is developed. In short, a total of three standard spectrum series - warm temperate desert, temperate desert, and temperate desert-steppe, and one special spectrum series - alpine steppe - are developed in the Tianshan Mts.

3.2 Montane forest / forest-steppe belt

Montane forest belt is an indicator of mountain environment in arid regions. Its appearance represents a relatively humid habitat. Clear delimitation of it involves the vertical limits of montane steppe belt below it and the alpine meadow above it. So, its determination is vital to constructing whole spectrum of altitudinal belts in arid mountain regions.

Any altitudinal belt should be an identical mountain ecosystem with a certain vertical range, spatial continuousness and distribution extent. This is clear in many mountains, as in the northern flank and Ili Valley of the Tianshan range where the montane forest belt can be clearly identified. But in some mountains, montane forests are only scattered in patches, as in the southern flank of Tianshan Mts. and in Kunlun Mts. In these mountain sections, there are montane forests, but no montane forest belt. This paper only distinguishes a montane forest-steppe sub-belt in the southern flank of Tianshan Mts. In the heartland of the study region (the Yulduz Basins), only a few patches of montane forests are found in the southeast mountain valleys, so even a montane forest- steppe sub-belt cannot be identified.

3.3 Montane steppe belt and alpine steppe sub-belt

Montane steppe belt is one of the major landscape types in the lower parts of Tianshan range, both in the two flanks and in Ili Valley in the west. It extends continuously on a large scale and constitutes the dominant belt, with a prominent position in the spectrum of altitudinal belts in arid mountain regions. In the higher parts of the southern flank, it is not alpine meadow but alpine steppe that develops in some sections. As a special case, it is classified only as a sub-belt.

3.4 Alpine meadow

Normally, alpine meadow belt appears above the forest belt and acts as an important token of high mountains. Almost in all high mountains, the delimitation of high mountain belt is based on the lower limit of alpine meadow and the upper limit of montane forest. Generally, alpine meadow always develops if the mountain is high enough. Only in extremely arid mountains, the alpine meadow belt is not clearly developed (Zhang 1995). In the entire high mountain areas of Tianshan Mts. is distributed this belt, only with a slight difference in the degree of development.

3.5 Nival and sub-nival belts

The main ridge of Tianshan Mts. is mostly above 4500 ~ 5000 m. The extremely high mountain regions are covered with extensive sparse vegetation belt (sub-nival belt) and snow-covered belt (nival belt). They are all the basic altitudinal belts in the extremely high mountains.

In some papers (Zhang and Xia 1995, Zhang and Li 1966) on the altitudinal belts of mountains in Xinjiang can be found more detailed divisions of altitudinal belts, such as subalpine meadow, subalpine steppe, desert-steppe, etc. They are mostly transitional landscape types. According to the definition of altitudinal belts (Zhang 2003), they cannot be treated as independent altitudinal belts, but as the internal difference of altitudinal belts. The desert-steppe belt identified by some geographers is actually the transition from desert to steppe belt, and its distribution is difficult to delimit. Internationally, mountains at elevations of 2000 ~ 2500 m are considered to be high mountains, but usually as subalpine or even middle mountains in China. Some authors argue that there is a montane meadow belt in the mountains of upper Ili Valley (Zhang and Xia 1995). Considering that the elevation of these places is above 1800 m, this meadow should be classified as alpine meadow. Some authors inadequately hold that there is an alpine desert belt in Tianshan Mts., for alpine desert is a special conception for the ecosystem in the northwestern Tibetan Plateau. The so-called "alpine desert" of Tianshan Mts. is actually a sub-nival landscape. Although a continuous montane forest belt does not exist in the southern flank of Tianshan Mts., there is a clear mixed forest-steppe belt above the montane steppe belt in some sections of the southern flank. To highlight this phenomenon, a montane forest-steppe sub-belt is designated. Finally, steppe with evident properties of alpine steppe belt is usually prominent just below the alpine meadow in some parts of the southern flank, and an alpine steppe sub-belt is added. The whole classification system of altitudinal belts for the study region can be generalized in Table 1.

Based on Table 1 and the digital method of altitudinal belts, the system of spectra of altitudinal belts in Tianshan Mts. can be digitized as in Fig.2 for the northern flank, Fig.3 for the southern flank, and Fig.4 for the Ili Valley in the west.

4 Spatial Models for the Spectra of Altitudinal Belts

4.1 Spectra of altitudinal belts in the northern flank

All the spectra of altitudinal belts have identical belts without exception. The difference only lies in the altitude and vertical range of the same belts (Fig.2). The temperate desert is the base belt with artemisia desert vegetation. Its lower limit is at elevations of 800 ~ 1000 m and upper limit generally at 1100 ~ 1500 m.

The montane steppe belt contains, in the upper part, communities of *stipa capillata* and *Festuca sulcata*, distributed mostly between 1550 (1700) m ~ 2150 m, even to 2500 m on sunny slopes. The lower part features artemisia (in eastern section) and salsola (in western section) communities at elevation of 1100 ~ 1500 (1700) m, virtually a desert-steppe sub-belt. In the steppe belt can be seen some shrub-steppe and meadow- steppe communities on some valley slopes. The montane forest belt is mostly at 1600 ~ 2800 m, with continuous distribution of Tianshan spruce (*Picea schrenkiana*) forest. Between Qitai and Mori in the east are coniferous and broad-leaved mixed forests of Tianshan spruce and *Populus davidiana*; and east of Barkol, between 42°50′~ 43°10′N and93° ~ 94°50′N, Xinjiang larch (*Larix sibirica*), appearing at 2200 ~ 2800 m with an annual precipitation of 300 ~ 500 mm, becomes the main component in the forest belt. In the lower parts, spruce and Xinjiang larch constitute mixed forests (CCXF 1989). In short, the upper part of the forest belt is a forest-meadow sub-belt, the middle part a typical forest sub-belt, and the lower part a forest-steppe sub-belt.

Alpine meadow also shows as an integral altitudinal belt at 2400 ~ 3900 m, characterized by well developed kobresia meadow. Typical alpine meadow appears at elevations of 2700 ~ 3600 m, with kobresia and tundra as the main vegetation. On the shady and relatively moist slopes, *Polygonum viviparum* can be found. Only on the quite moist slopes, e.g. in the mountains south of Manas, can develop colorful rich-in-species meadow.

The snowline appears at 3600 ~ 4200 m, quite low in arid regions. This explains the large-scale development of snow and ice in the northern flank of Tianshan Mts.

4.2 Altitudinal belts in southern flank

The altitudinal belts develop from the warm temperate desert on the southern slope. Desert penetrates the mountains deeply due to little snow in winter and the dry climate. The forest features scattered distribution, sparse canopy, high tree line, and pure species.

Table 1 Altitudinal belts in Tianshan Mountians

Northern flank	Southern flank	Ili Valley	Yulduz Basins
Nival belt	Nival belt	Nival belt	Nival belt
Sub-nival belt	Sub-nival belt	Sub-nival belt	Sub-nival belt
Alpine Meadow belt	Alpine meadow belt	Alpine Meadow belt	Alpine meadow belt
Coniferous forest belt	(Alpine steppe sub-belt)	Coniferous forest belt	Alpine steppe belt
Montane steppe belt	Montane steppe belt	(Broad-leaved forest sub-belt)	
Temperate desert belt	(Desert-steppe sub-belt)	Montane steppe belt	
	Warm temperate desert	Temperate desert-steppe belt	

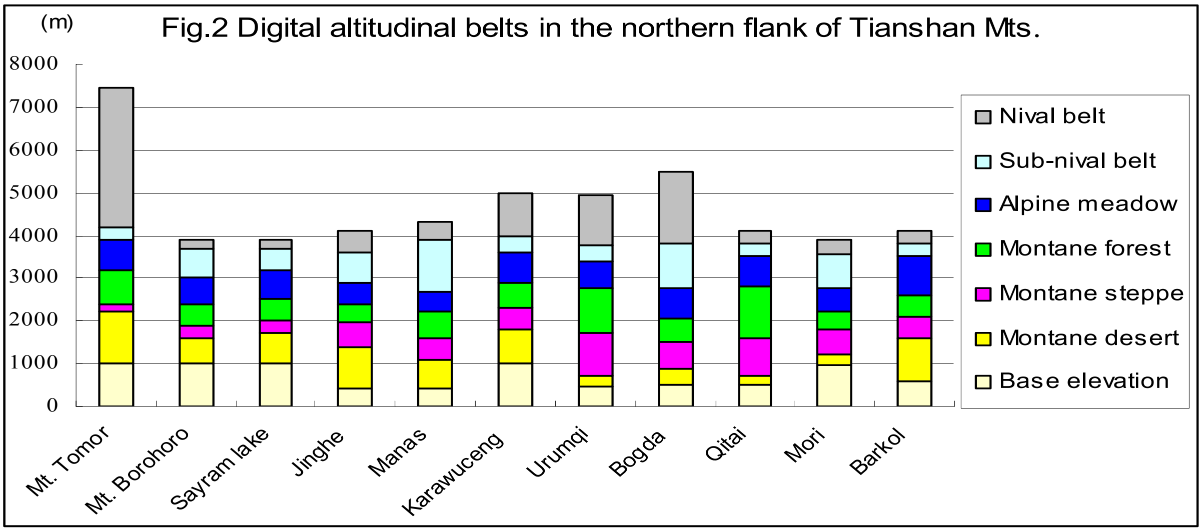
Fig.2 Digital altitudinal belts in the northern flank of Tianshan Mts.
(m)
8000
7000
6000
5000
4000
3000
2000
1000
0
Nival belt
Sub-nival belt
Alpine meadow
Montane forest
Montane steppe
Montane desert
Base elevation
Mt. Tomor
Mt. Borohoro
Sayram lake
Jinghe
Manas
Karawuceng
Urumqi
Bogda
Qitai
Mori
Barkol

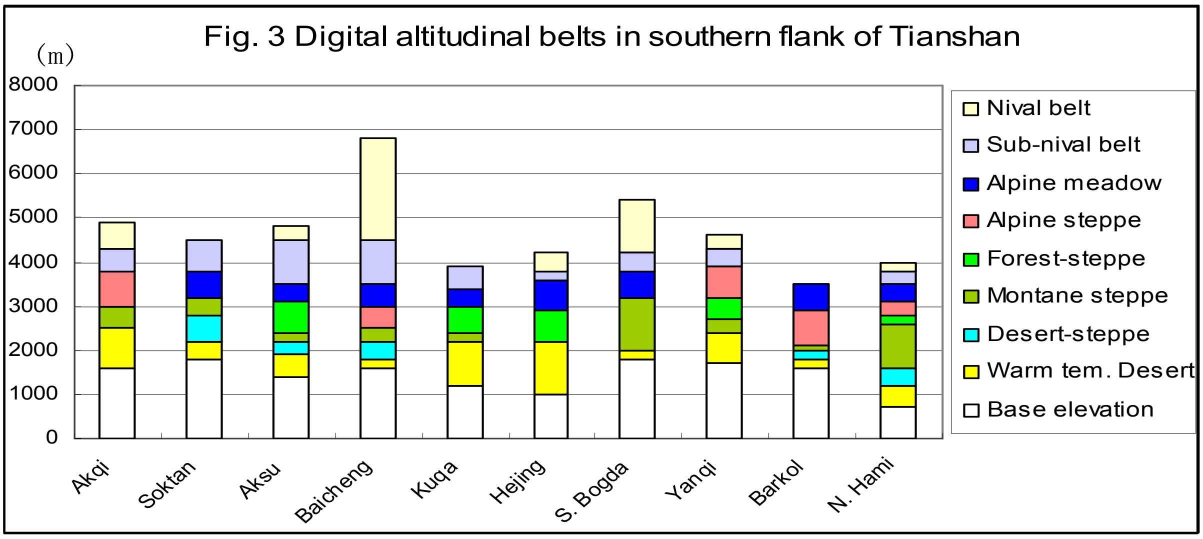
Fig. 3 Digital altitudinal belts in southern flank of Tianshan
(m)
8000
7000
6000
5000
4000
3000
2000
1000
0
Nival belt
Sub-nival belt
Alpine meadow
Alpine steppe
Forest-steppe
Montane steppe
Desert-steppe
Warm tem. Desert
Base elevation
Akqi
Soktan
Aksu
Baicheng
Kuqa
Hejing
S. Bogda
Yanqi
Barkol
N. Hami

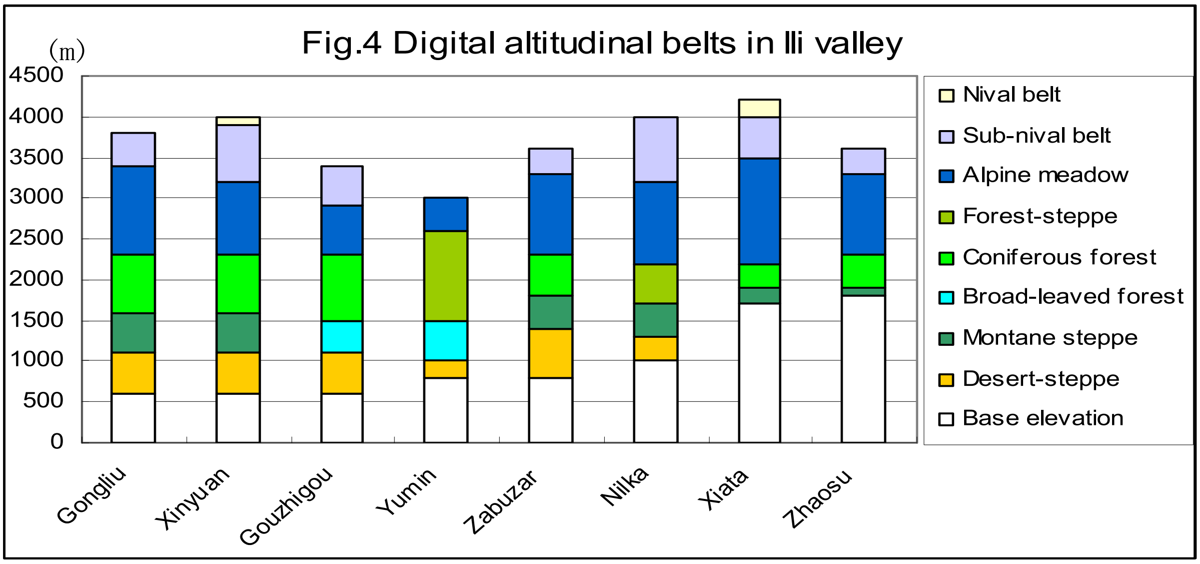
Fig.4 Digital altitudinal belts in Ili valley
(m)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Nival belt
Sub-nival belt
Alpine meadow
Forest-steppe
Coniferous forest
Broad-leaved forest
Montane steppe
Desert-steppe
Base elevation
Gongliu
Xinyuan
Gouzhigou
Yumin
Zabuzar
Nilka
Xiata
Zhaosu

Actually, neither subalpine meadow nor continuously distributed forests exist. Only on some shady slopes, can some small patches of forest be seen in the subalpine and alpine areas. But their distribution is quite different from west to east. In the mountains north of Yanqi in the east, clumps of shrub develop on the steep and relatively humid shady slopes from 2200 m to 3000 (3500) m. To the west of Kuqa, many patches of forest occur at elevations of 2000 ~ 2800 m. The montane desert, montane steppe and highly desiccated alpine vegetation belts are clearly differentiated in vertical range. In the central section of the southern flank, the montane forests are confined to steep shady slopes in the sub-alpine belt due to very dry climate. Montane desert and steppe almost occupy the whole middle mountains. Generally, the montane desert belt appears from 1400 (2100) m to 1750 (2700) m, with the upper part as artemisia desert and the lower part as semi-shrub salsola desert; the montane steppe belt at 1750 (2700) ~ 2200 (3000) m mainly consists of artemisia and festuca communities. The montane forest-steppe sub-belt at 2200 (3000) ~ 2900 (3600) m is characterized with patches of spruce forests on shady slopes or shrubs on stony slopes and steppe on sunny slopes. The alpine meadow belt at 2900 (3600) ~ 3200 (4000) m contains such communities as *Kobresia capilliformis, C. pamiroalaica*, and *Festuca supine*. The snowline extends at an elevation of 4000 to 4500 m.

4.3 Altitudinal belts in Ili Valley

The base belt in Ili Valley is temperate artemisia desert-steppe. Above it is a montane steppe belt characterized with *Bothriochloe ischaemum* communities. Thanks to the relatively humid climate in the mountains with a rainfall of 800 ~ 1000 mm, montane forest and alpine meadow belts are well developed. The alpine meadow belt has a wide vertical range from 1400 m to 3500 m alternating with montane steppe and forest belts. That is why some geographers distinguished the so-called montane meadow and subalpine meadow belts.

The montane forest belt has a lower limit at only about 1100 m. Its structure is complex: between 1400 m and 2700 m is a coniferous forest sub-belt, and downward is a mixed forest sub-belt with *Picea schrenkiana* and *Populus pseudotremula* or *Betula tianshanica*. Further downward, namely between 110 m and 1600 m, appears a broad-leaved forest co-existing with shrub-steppe, especially including the endemic wild fruit forest, such as *Malus sieverss, Armeniaca vulgaris* and *Juglans regia*. Typical alpine meadow occurs from 2300 (2600) ~ 2900 (3500) m. Its upper part is kobresia meadow (*Kobresia, Poligonum viviparum, Leontopodium alpinum*), and the lower part contains *Alchemilla rubens, A. krilovii, Phlomis oreophil, Geranium albiflorum, etc.*

4.4 Altitudinal belts in the heartland of Tianshan Mountains

Situated in the heartland of Tianshan Mountains, the Bayanbulak region covers two intra-montane basins - the Grand Yulduz Basin and the Minus Yulduz Basin, separated by the Erbeng Mountains. The bottoms of the basins lie at 2400 ~ 2700 m, and the mountains at 5000 m and above. Alpine steppe and alpine meadow are widespread, serving as alpine pastureland. In the north, alpine steppe is distributed at 2500 ~ 2800 (2900) m with a horizontal distance of 16 ~ 20 km. In the south, alpine steppe appears at 2450 ~ 2750 m with a horizontal width of only 3 ~ 5 km. Upwards, the alpine meadow belt appears at 2700 ~ 3200 m on shady slopes and 2800 ~ 3500 m on sunny slopes. The snowline extends between 4300 and 4500 m.

4.5 Areal differentiation of altitudinal belts

4.5.1 East-west differentiation

Just like the climatic pattern of aridness in the central section and relative humidness in the western and eastern sections, altitudinal belts occur lower in the center and relatively higher in the eastern and western ends. This is especially true for the montane forest belt (Fig. 2). In the northern flank, the montane forest belt develops at high altitudes, namely above 2000 m, in the west within a vertical range of only 400 m in Kokirqin Mts. and 700 m in Jinghe. From Jinhe eastwards to Usu, the belt lowers and the vertical range widens; further eastwards, from Manas to Urumqi, it appears at 1600 ~ 2800 m within a vertical range of 1200 m. Still eastwards, between Mori and Barkol are low and stony mountains with no distribution of forests. Still more eastward to the mountains north of Hami, forests occur but rise to 2100 ~ 2900 m, and the dominant species of trees is *Larix sibirica* not *Peacia schrenkiana*. This pattern also occurs in the southern flank.

4.5.2 Comparison between the northern and southern flanks

As mentioned above, warm temperate desert is the base belt in the southern flank, while temperate desert the base belt in the northern. The climate is drier in the southern flank than in the northern flank. As a result, desert rises higher in the southern flank than in the northern flank. For example, it is at 800 ~ 1000 m in the northern flank, and above 2000 m in the southern flank. Other belts have the same pattern: higher in the southern flank than in the northern flank, namely 500 m higher for alpine meadow and 500 ~ 700 m higher for snowline. An integral montane forest belt develops in the northern flank but not in the southern flank where only occur patches of forests and shrubs. This makes the most obvious contrast in landscape between the southern and northern flanks.

4.5.3 Comparison between the interior and the outside

At elevations of 2400 ~ 2700 m are forests in the northern flank and forest-steppe in the southern flank, but there is no distribution of forest in Bayanbulak region in the heartland of Tianshan Mts. Extremely low temperature in winter in Yulduz Basin leads to this contrast, as mentioned in the upper sections of this paper.

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