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Patterned ground on the northern side of the West Kunlun Mountains, western China

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Abstract

Mapping of earth hummocks, sorted nets, sorted stripes and lobes, small and large fissure -polygons, and some other periglacial phenomena such as rock glaciers, debris-mantled slopes, and involutions were conducted on the northern slopes of the West Kunlun Mountains, northwestern margin of the Tibetan Plateau, based on field research in 1987. Many different kinds of patterned ground occur in the zone above 5200 m in altitude, while in the zone below 5200 m, patterned ground occurs only in limited places. This intensive distribution in the higher zone may be due to the existence of continuous permafrost, while in the lower zone the patterned ground develops in places where the soil moisture condition is favorable.

1. Introduction

Snow- and ice-free areas of high mountain regions are situated in periglacial environments, where ground frost develops various periglacial phenomena on and beneath the ground surface. To assess the periglacial environments is one of the most important clues to understand climatological, geomorphological, and ecological situations in the high mountain region. After the first assessment of the periglacial vertical -zonation on a global scale by Troll (1944), the vertical distribution of patterned ground has been studied in various mountain chains of the earth (*e.g.* Graf, 1971; Höllermann, 1972; Ellenberg, 1974; Iwata *et al.*, 1976; Iwata, 1986). Each of these zonations represents a different feature: The features vary with the location.

On and around the Qinghai-Xizang (Tibet) Plateau many periglacial phenomena have been observed and mapped (*e.g.* Cui, 1981; 1982). Detailed studies were concentrated in the northeastern corner of the Plateau, *i.e.*, Quilin Shan and the East Kunlun Mountains (*e.g.* Lanzhou Institute of Glaciology and Cryopedology, Academia Sinica, 1983; Liang and Cheng, 1984; Cui, 1985; Kuhle, 1985; 1987; Koizumi, 1986; Wang, 1987; Koaze *et al.*, 1988), and the northern side of the Himalayas (*e.g.* Zheng *et al.*, 1982). In contrast, in the northwestern part of the Tibetan Plateau including the West Kunlun Mountains, in which area the periglacial domain presumably extends very much because of its high snow line and relatively gentle topography, only few studies have been carried out (Geomorphology Group in the Comprehensive Expedition Team to Xinjiang, 1978; Li, 1987; Li and He, 1989).

In July, 1987, we carried out field research on periglacial phenomena on the northern side of the West Kunlun Mountains as members of the "Sino -Japanese Joint Glaciological Expedition in West Kunlun Mountains 1987" (Zheng *et al.*, 1988). Based on this field work, we illustrate the distribution of patterned ground and discuss the characteristics of the periglacial environment of the area.

2. The study area

The West Kunlun Mountains, located in the northwestern margin of the Tibetan Plateau, are

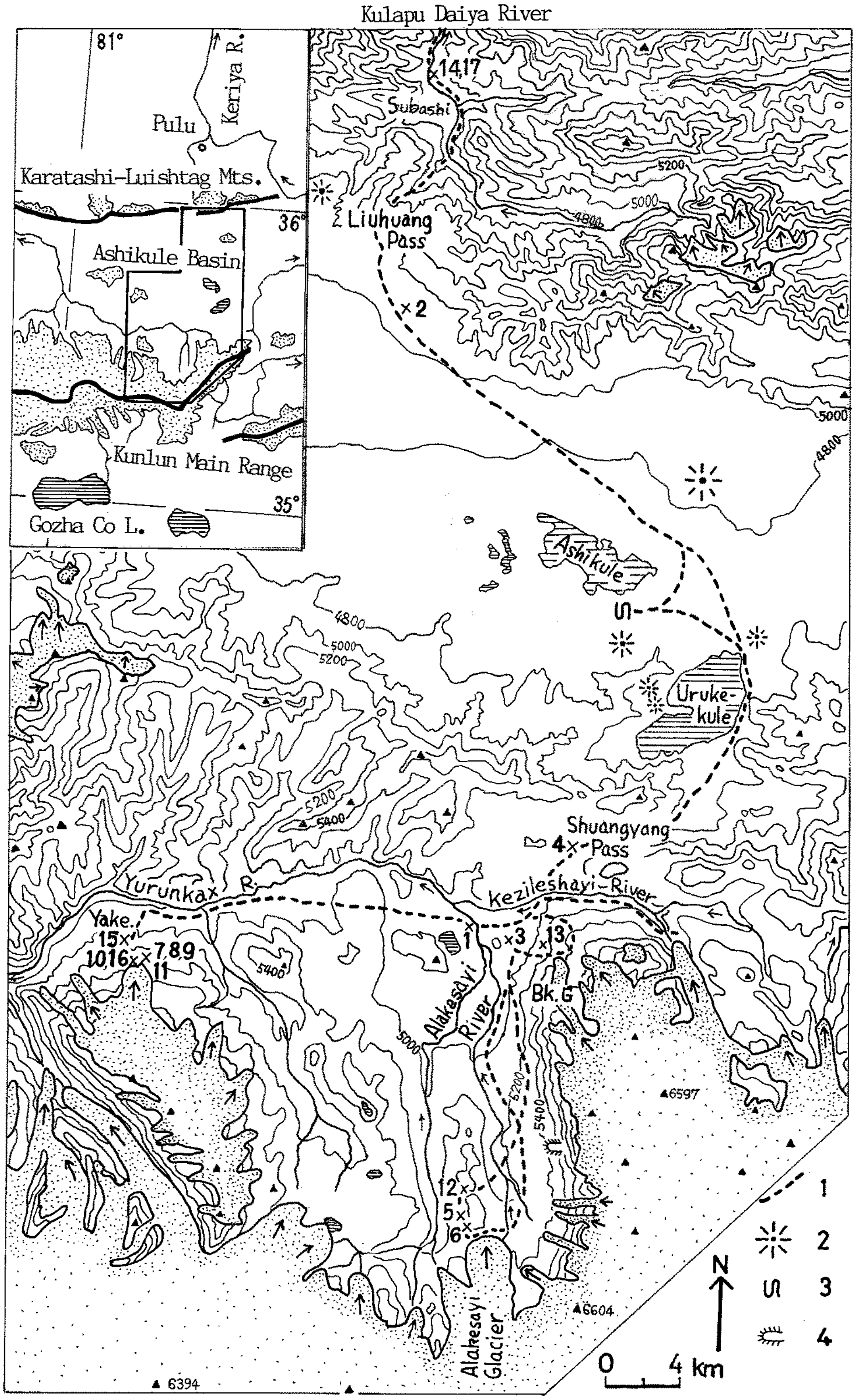

Fig. 1. Index map of the patterned ground on the northern side of the West Kunlun Mountains. Numbers indicate the locations of the patterned ground shown in Table 1. The contour intervals are 200 m. 1: Research routes, 2: Volcanic cone, 3: Involution, 4: Rock glacier.

composed of the high and relatively gentle main range and the relatively low but steep north range (Karatashi - Liushtag Shan). Between these two ranges there exists a high plateau-like basin, called Ashikule Basin, with young volcanic cones (Fig. 1).

Although climatic conditions of the area are rather dry as shown in Li and He (1989) and the present firn lines on the glaciers is about 5800 m a.s.l. in the area (Scientific Expedition to the Qinghai-Xizang Plateau, 1986), the higher part of the main range is covered with extensive glaciers. The mountains border the Taklimakan Desert on the north without any dense vegetation zone: neither dense herbaceous vegetation nor forest exists on the north slopes of the Kunlun Mountains. Grasses, cushion plants, and dwarf shrub sparsely occur on a vast dry land area.

A geological map of the area which is assumed to have been revised using Landsat images exists (Chen, 1984). The main parts of the mountain ranges are composed of crystalline rocks such as granite, gneiss, and syenite, but a large part of the study area consists of phyllitic sandstone and siltstone. The eastern half of the Ashikule Basin was occupied by basaltic lava, and the other areas of the basin by Pleistocene and Holocene fan gravels.

Our research routes are indicated in Fig. 1: Our observations of periglacial phenomena were limited to relatively small areas along our routes.

3. Distribution of patterned ground

Patterned ground has been regarded as a good indicator of periglacial environments, but it occurs only in places which exist suitable conditions. The frost action occur intensively by both low temperatures and frequent freeze-thaw cycles with abundant moisture content in soil, while restrained by rough materials and dense vegetation cover. Debris movement in the earth by frost action is frequently obliterated by other geomorphic processes such as fluvial and rapid mass movement processes. Thus, considering the distribution of patterned ground, we should pay attention to all surrounding environments. Figure 1 shows a horizontal distribution of patterned ground which we observed in the study area. Patterned ground exists in relatively in limited areas: it particularly occurs in areas adjacent to glacier termini on the northern slope of the Kunlun main range, while no patterned ground has been found in the main part of the Ashikule Basin covered by volcanic lava, tephra, and alluvial fan sediments (Fig. 2).

Fig. 2. The ground surface of Ashikule Basin is covered with lava and tephra. No distinct patterned ground is distributed on the surface. A young volcanic cone, called the Ashikule Volcano, erupted in 1951.

Types of patterned ground and their locations are shown in Table 1. No pingo or other large frost mound has been found, but many ones were reported on the south side of West Kunlun (Li, 1987) as well as East Kunlun (*e.g.* Kuhle, 1985; Koizumi, 1986). Some noticeable features are given below:

3.1. Incomplete earth hummocks and sorted net

They were found on a dry river bed at Subashi (4130 m in altitude), located in a small basin in the upper reaches of the Kulapu Daiya River, which is a tributary of the Keriya River (Locs. 14, 17). They are the lowest patterned ground in the area, because there is no room for patterned ground in the lower section of the Kulapu Daiya where steep rocky valley slopes form gorges. No solifluction feature such as indistinct lobes could be observed even on the few gentle slopes of moraines which had been built in the main valley by past glaciers from tributary glaciers.

3.2. Earth hummocks

Despite of the most common patterned ground in the lower altitudes of humid mountains, earth hummocks are rarely observed on the north side of West Kunlun, owing to the lack of dense vegetation cover. A few patches of earth hummocks were found in turf along the small stream from the glacier above Yakebaketake at altitudes of 5230-5300 m (Locs. 15, 16).

Table 1. Types and locations of patterned ground.

Loc. No.	Patterned ground Type	Location	Altitude (m)	Additional comment
1	Large-scale fissure polygons	Confluence of Alakesayi and Kezileshayi Rivers	4920	On old moraine, nearly square plans with a 5-10 m side
2	Small-scale fissure polygons	Southeast of Liuhuang Pass	5040	On fan surface, a 2-3 m side, partly inactive?
3	Small-scale fissure polygons	Frontal flat place of Bulake-bashi Glacier	4960	On fan surface
4	Large-scale sorted patterned ground	Shuangyang Pass	5000	Near dried pool
5	Large-scale sorted net	Near terminus of Alakesayi Gl.	5400	Flat place on the moraine
6	Large-scale sorted stripes	Near terminus of Alakesayi Gl.	5400	Debris mantled slopes
7	Large-scale sorted stripes	Near Yakebaketake	5350	Debris mantled slopes 2 m intervals
8	Large-scale sorted stripes	Near Yakebaketake	5400	On ridge
9	Sorted lobes	Near Yakebaketake	5400	On ridge
10	Debris islands	Near Yakebaketake	5360	Inside of recent moraine
11	Sorted net	Near Yakebaketake	5310	On ridge
12	Small sorted net and stripes	Ridge between rivers from Alakesayi Gl.	5400	Flat surface on pass, fine materials
13	Sorted net	Terminus of Bulakebashi Gl.	5000	In the hollow on a rocent moraine
14	Sorted net	Subashi	4160	Incomplete, Dry river bed
15	Earth hummocks	Near Yakebaketake	5260	Along stream from glacier
16	Earth hummocks	Near Yakebaketake	5300	Inside of moraine
17	Earth hummocks	Subashi	4160	Dry river bed

The locations are shown in Fig. 1

3.3. Sorted patterned ground

Most sorted patterned ground exists at high altitude above 5200 m a.s.l. Sorted polygons, debris islands, sorted lobes, and sorted nets occupy flat and gently sloping surfaces of both moraines and bedrocks. In particular, large-scale sorted stripes and sorted lobes are extensively distributed on debris-mantled slopes composed of phyllitic rocks (*e.g.* Fig. 3). Near the terminus of the Alakesayi Glacier (Locs. 5, 6), it was observed that melt water flowing out from permafrost drained through lines of large stones of stripes and furrows surrounding cells of sorted polygons, and fine materials in the central parts of the patterned ground were saturated with melt water. Small-scale sorted net and stripes also occur at the higher altitude of 5400 m: these small features are due to the mudstone which easily break into small pieces (*e.g.* Loc. 12).

Fig. 3. Large scale sorted stripes and lobes on a debris-mantled slope. Loc. No. 7 at near Yakebaketake (5350 m a.s.l.).

Sorted patterned ground was observed at two localities around 5000 m in altitude: one is large scale sorted nets in the vicinity of a dried pool on Shuangyang Pass (5000 m)(Loc. 4) and the other is sorted nets at the bottom of the hollow in the recent moraine of the Bulakebashi Glacier (Loc. 13). Thus, they occurred in places where enough water had been supplied on some special occasions.

3.4. Fissure polygons

On the piedmont fan to the southeast of Liuhuang Pass, small scale fissure polygons occur in a wide area along an abandoned road (Loc. 2). The same polygons were found on the fan in front of the Bulakebashi Glacier (Loc. 3). Large-scale fissure polygons 5-10 m long were formed on the old moraine at the confluence of the Alakesayi and Kezileshayi Rivers (Loc. 1, Fig. 4). The ground surfaces of these three localities are composed of relatively fine materials such as sand and silt, but a few small stones are scattered. The fissures of these polygons, which have no sharp edges, were filled with wind-blown sand, but we believe that they open by thermal contraction in the severe coldness in winter as many authors have reported. We have not confirmed the existence of ice wedges or ice veins underneath the fissures by digging a pit.

Fig. 4. Large scale fissure polygons on the old moraine at the confluence of the Alakesayi and Kezileshayi Rivers (4920 m a.s.l., Loc. No. 1).

4. Other periglacial phenomena and landforms

4.1. Involution

Except for the above-mentioned small scale fissure polygons to the southeast of Liuhuang Pass, no distinct patterned ground is distributed on flat surfaces in the Ashikule Basin. Small involution of volcanic glass was found south of Ashikule Lake (Fig. 5).

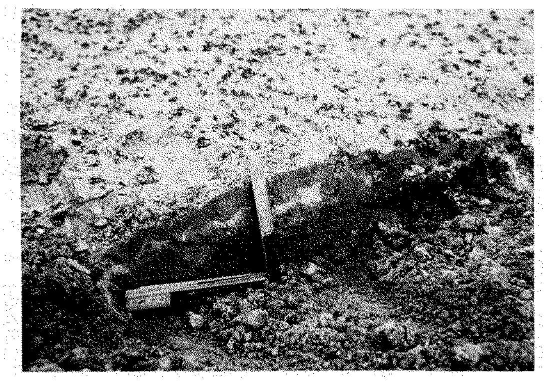

Fig. 5. Involution of volcanic glass south of Ashikule Lake (4720 m).

This means that the lack of patterned ground does not imply that the frost action does not occur in the basin. This is also supported by the fact that patterns of many festoons which are likely to be formed by solifluction were observed on slopes of volcanic cones and on Liuhuang Pass; both were covered by volcanic ash and scoria.

4.2. Debris-mantled solifluction slopes

They are one of the most peculiar landscapes in the West Kunlun Mountains as well as the northwestern part of the Tibetan Plateau. Most valley slopes around Subashi, the upper reach of the Kulapu Daiya River, have rectilinear profiles, ranging from 23-30° in angle, and are covered with relatively fine materials which seem to originate mainly from tephra, while the surface rubble layer is very thin. Some solifluction features such as indistinct lobes and stripes were observed on these slopes, therefore frost creep and gelifluction may occur. On the north slope of the Kunlun main range, distinct debris-mantled slopes are situated above around 5200 m in altitude except on steeper slopes over 35° and snow- and ice-covered slopes. As mentioned above, large-scale sorted stripes occur in almost places on these debris mantles; This fact suggests that intensive gelifluction caused by saturated active layer of the permafrost act effectively on these slopes. Erratic boulders existing on these slopes show that these slopes were occupied by glaciers in the Last Glacial, therefore these debris mantles were formed by intensive frost shattering in the past 10,000–15,000 years after being released from glaciers.

On the other hand, exposed bedrock slopes with only little debris-mantle are distributed on the gentle mountain flanks between Shuangyang Pass and the round hills west of the confluence of the Alakesayi and Kezileshayi Rivers, at altitudes between 4900 m. We consider that the almost complete lack of debris cover is due to very fragile phyllitic rocks where disintegrated finer materials by frost shattering have been blown away by wind.

4.3. Rock glacier

Distinct rock glaciers were identified on the east valley wall of the lower valley of the Alakesayi Glacier (see Fig. 1). The altitude of the terminus is located at about 5300 m in altitude. They belong to the tongue type and represent the same features as a terminal moraine of a glacier. They are located in the central part of a large-scale landslide topography so that the origin of the rock glacier seems to be a glaciogenic rock glacier which the pre-existing glacier ice was covered with the landslide mass.

5. Vertical distribution of patterned ground

Vertical distribution of the patterned ground in this area is schematically illustrated in Fig. 6, which

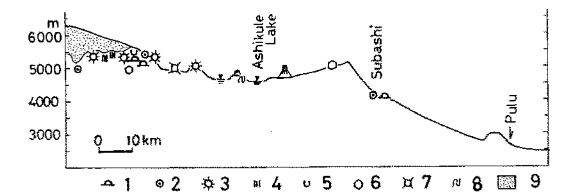

Fig. 6. Vertical distribution of patterned ground in the north side of West Kunlun. The section indicates landforms along the research route. 1: Earth hummocks, 2: Small-scale sorted polygons, 3: Large-scale sorted polygons, 4: Sorted stripes, 5: Sorted lobes, 6: Small-scale fissure polygons, 7: Large-scale fissure polygons, 8: Involution, 9: Glacier.

shows that the vertical zonation is quite different from those of humid mountains where several zones are arranged from the lower to the higher altitudes (*e.g.* Iwata, 1986). In this area, many different kinds of patterned ground occur at the same altitude. The earth hummocks which are dominant in the lower periglacial zone (turf-banked solifluction zone) in other mountains were found among sorted polygons which occur mainly in the higher zone (frost shatter zone) in general (Iwata, 1986). Most patterned ground is concentrate above 5200 m, which coincides roughly with the upper limit of grass vegetation. Although we did not carry out a detailed ecological survey of vegetation, it is clear that the plant cover decreases above 5200 m: The coverage rate becomes below a few percent. The highest occurrence of the patterned ground was observed at an altitude of 6198 m on the margin of the Chongce Ice Cap on the southern side of the West Kunlun Mountains.

6. Discussion

Li (1983) discussed the vertical zonation of a periglacial environment and concluded that the Kunlun Mountains are of the continental desert type, where frost shattering is the main weathering process and all mountain surfaces except sharp ridges are governed by periglacial slope processes. In fact, Li (1987; 1989) has reported that almost all kinds of periglacial phenomena are distributed in the northwestern part of the Tibetan Plateau including the south slope of the West Kunlun Mountains. This seems to indicate that periglacial phenomena develop very well in this region. However, compared with the large area covered in Li Shude's reports, the areal proportion of the areas in which periglacial phenomena occur in small patches is very small. On the southern side of the West Kunlun Mountains between Gozha Co Lake and the Chongce Ice Cap, we unexpectedly observed that the distribution of patterned ground is extremely limited in small areas, and types of phenomena are poor in variety.

On the northern side of the West Kunlun Mountains, the intensive distribution of sorted patterned ground is limited to above 5200 m in altitude as mentioned above. Accordingly, the lower boundary of the continuous sorted patterned ground can be drawn at about 5200 m in altitude. In other words, the zone above 5200 m is distinguished as a real frost shatter zone. This corresponds with the zone above about 5500 m on the south slope below the Chongce Ice Cap, where large scale sorted circles and debris islands occupy the entire ground surface (Li, 1987, and our observations). The frost shatter zones seem to be fringes of the glacial area on both sides. The dense distribution of patterned ground in this zone may be due to the existence of continuous permafrost in an extremely shallow active layer and also of frost-susceptible phyllitic rocks and clay-rich glacial deposits.

On the other hand, judging from the distribution of patterned ground, below 5200 m in altitude, it occurs only in limited places where soil moisture content may be sufficient to cause frost disturbances in the soil. This suggest that the distribution of patterned ground below 5200 m governed by soil moisture content. Li (1987) reported that the lower limit of the periglacial zone (lower limit of solifluction) ranges from 3800 to 4000 m on the southern side of the West Kunlun. On the northern side, the lower limit of solifluction seems to be at almost the same altitude as the southern slopes.

On the southern side of the Kunlun main range, the lower limits of continuous permafrost and sporadic permafrost are 4800 m and 4600 m, respectively (Li, 1987). On the northern side of the Kunlun Mountains, the lower limit of permafrost has not been confirmed yet. The fissure polygons, however, suggest the existence of ground ice and/or permafrost. On the other hand, according to the ground temperature measurement (Fushimi, H., personal communication), the temperature gradient in soil did not indicate the existence of permafrost at altitude around 5000 m on the northern slopes during our research. Further discussion is required to solve this different interpretations.

Compared with the vertical zonations of periglacial phenomena in some places in the East Kunlun Mountains (Cui, 1981; 1982; Kuhle, 1985; Koaze *et al.*, 1988), it is very clear that the periglacial zones in West Kunlun shift to higher altitude than those in East Kunlun (Fig. 7). The zone of vegetation-covered patterned ground (zone of bound solifluction) is not distinct in West Kunlun. Although detailed discussion

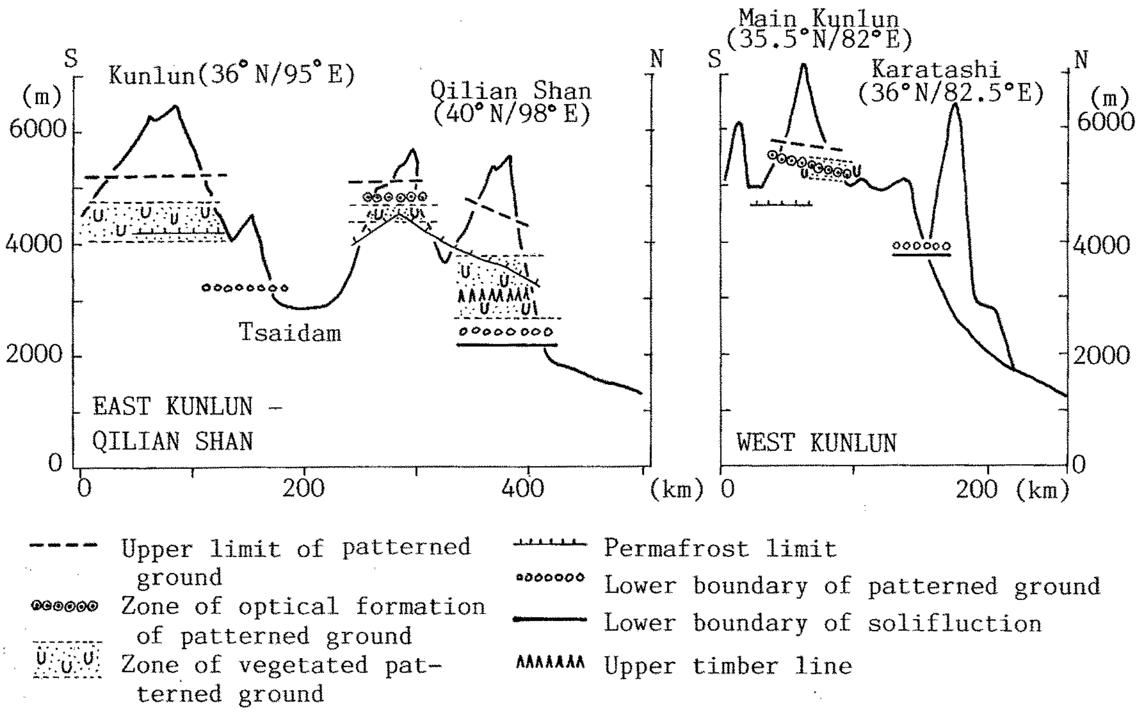

Fig. 7. Difference of vertical zonations of the periglacial phenomena between the the East Kunlun and Qilian Mountains (after Kuhle, 1985) and the West Kunlun Mountains.

should be done based on the climatological data which the expedition team observed, it is safely stated that these difference may be due to the difference of dryness in both regions. The dryness may imply not only in climatic conditions but also in edaphic conditions which existence of water permeable volcanic materials. The West Kunlun Mountains may have one of the highest periglacial zone in the world.

Acknowledgments

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