Permafrost and Periglacial Processes, Vol. 6: 265–271 (1995)

Short Communication

Gelifluction in the Alpine Periglacial Environment of the Tianshan Mountains, China

Liu Gengnian

Department of Geography, Peking University, Beijing, China

Xiong Heigang

Department of Geography, Xinjiang University, Urumqi, China

and

Cui Zhijiu

Department of Geography, Peking University, Beijing, China

ABSTRACT

Gelifluction in the periglacial zone of the Tianshan Mountains occurs at 2500–3600 m above sea level on north-facing slopes. Abundant groundwater, fine grained sediments and slopes 10°–30° favour gelifluction. Most gelifluction forms are lobate, a few are tongue-shaped. The mean surface rate of movement is 11.14 cm/a; the front advancing rate is 1.86 cm/a. The moving rate in the middle part is greater than at the sides of gelifluction lobes, the mean rates being 3.1 cm/a and 0.86 cm/a, respectively.

RÉSUMÉ

La gélifluxion dans la zone périglaciaire des montagnes de Tianshan se produit à 2500 m au dessus du niveau de la mer sur les pentes exposées au N. L'abondance d'eau dans le sol, des sédiments de granulométrie fine ainsi que des pentes de 10 à 30° favorisent ce processus. La majorité des formes de gélifluxion sont des lobes mais il existe aussi des langues. La vitesse moyenne du déplacement est de 11,4 cm par an; la vitesse d'avancée du front étant de 1,86 cm par an.

La vitesse est plus grande dans la partie centrale des lobes et moindre à proximité des côtés, les vitesses moyennes étant respectivement en ces deux endroits de 3,1 cm par an et de 0,86 cm par an.

KEY WORDS: gelifluction; Tianshan

CCC 1045-6740/95/030265-07

Received 20 April 1995
Accepted 9 June 1995

INTRODUCTION

The Tianshan Mountains, which extend east–west in western China, are about 1700 km long and 250–350 km wide from south to north. Most ridges are 4000 m ASL; the summit of Tomuer is 7435 m ASL. Precipitation decreases from west to east and from north to south. The inner mountain area has more precipitation than the marginal areas. Temperatures on north-facing slopes are 5 °C or so lower than those at the same altitude on south-facing slopes. The research area is in the middle part of the mountains. On the north-facing slope of the mountains near Urumqi City, between 1000 and 1500 m ASL, the mean annual precipitation is 300 mm/a. At altitudes of 1500–3000 m, the mean annual precipitation is over 400 mm/a, with the heaviest precipitation of 600 mm/a at 2500 m ASL. Above 3000 m, the mean precipitation is 430–440 mm/a (Yang, 1990). There is a temperature inversion at 2000–2500 m ASL on the north-facing slope. The annual mean temperature is 5.7 °C at Urumqi (654 m ASL), 0.2 °C at Tianshan Glacial Research Station (2130 m ASL), −0.3 °C at Daxigou Meteorological Station (3450 m ASL), and −7.1 °C at Empty Cirque (3805 m ASL).

MEASUREMENTS AND RESULTS

The measurements made include topography of the research sites, morphological characters of the gelifluction, the surface and frontal moving rate, soil profile composition and water content. Field research was conducted at Laerdun Pass (43°N, 84°E) in August 1990 and again in 1991 and 1992. Two sites were selected at the head area of Urumqi River (43°N, 86–87°E) in August 1990 and 1991. One site is an area between no. 3 glacier and no. 4 glacier (3600 m ASL) and a fourth site is at Wangfeng Platform (3300 m ASL).

Topographic and Morphological Characteristics

Gelifluction at Laerdun Pass (TLG) occurs at 2800–3000 m ASL on the north-facing slopes (Figure 1). The slope orientations are 13–17°NE, the slope gradients are 12–31°, the mean slope gradient is 20°. Table 1 shows the morphological parameters of the gelifluction at Laerdun Pass and that at the head area of Urumqi River (NL). The length of gelifluction lobes is shorter than the width. The length to width ratio is 0.33–1.51, with

Figure 1 Edge of gelifluction lobe at Laerdun Pass (2880 m ASL), Tianshan Mountains, China.

Table 1 Morphology of gelifluction forms, Tianshan Mountains, China.

Site	Dimensions (m)			Slope direction	Slope				Altitude (m ASL)
	Length	Width	Height			Surface	Front	Ground	
					West	19°	59°	23°	
TLG-1	18.3	25.7	2.5	15°	Middle	10°	52°	26°	2890
					East	17.5°	51°	24°	
					West	7°	18°	31°	
TLG-2	8.55	17.5	1.55	15°	Middle	29°	51.5°	12°	2895
					East	22°	58°	11°	
					West	25°	65°	22°	
TLG-3	28.4	30	2	13°	Middle	27°	61°	17.5°	2900
					East	20°	70°	21°	
TLG-4	15.7	10.4	1.65	17°		16°	60°	20.5°	2910
TLG-5	6.5	20	1.67	13°		22°	61°	13°	2910
TLG-6	7	15	1.8	15°		30°	65°	25°	2880
NL-1	17	10	4	275°		15°	37°	20°	3560
NL-2	14	6	1	200°		10.5°	27.5°	15°	3560
NL-3	10	8	1.3	295°		2°	33°	10°	3560
NL-4	16.5	18.5	0.7	18°		12°	71°	25°	3550
NL-5	27.6	20.5	1.13	20°		12°	65°	20°	3350

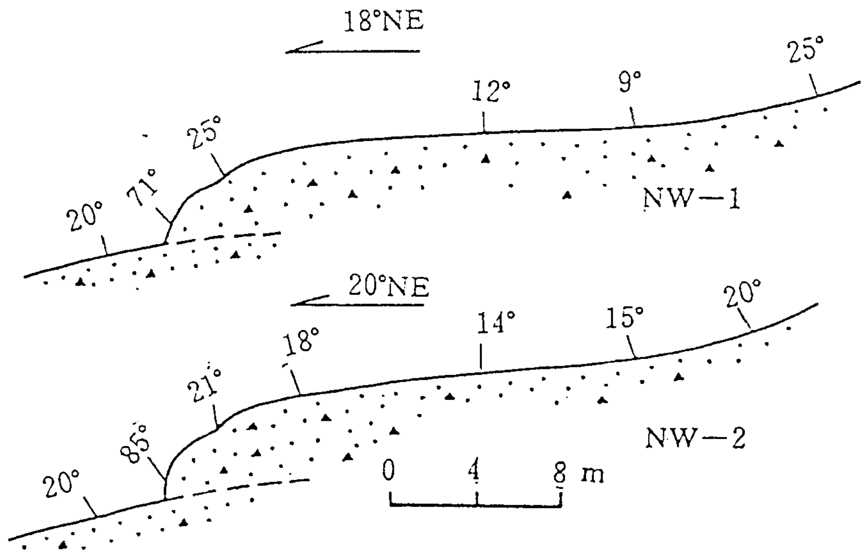

Figure 2 Cross-section profiles and surface slope gradients of gelifluction lobes, Wangfeng Platform, head area of Urumqi River, Tianshan Mountains, China.

a mean ratio of 0.74. The surface gradient of the gelifluction is 7–30°, with a mean gradient of 20°. The slope gradient of the area where gelifluction occurs widely varies between 12° and 31°, with a mean gradient of 20°.

Gelifluction in the head area of Urumqi River occurs at 3350–3560 m ASL. The length to width ratio is 0.80–2.3, with a mean of 1.34. Gelifluction develops on north-facing slopes (275°NW–20°NE). Figure 2 gives the typical gradients on the gelifluction lobes.

Profile Characteristics

At Laerdun Pass, a gelifluction lobe was excavated (Figures 3, 4). Vein-ice appears at a depth of 1.65 m. This suggests that permafrost exists and the thickness of the active layer is approximately 1.90 m.

Based on field data, the gravel content is less than 20%. The grain-size composition (Table 2) shows that the sand content ranges between 22.3 and 67.4%; the clay content ranges between 7.4 and 25.8%. The water content ranges between 9.7 and 75.2%. The relationship between grain size and water content indicates that the higher the clay content, the higher is the water content. The section characteristics and water content are shown in Figure 4.

Rates of Surface and Frontal Movement

The dip-angle method was adopted to measure the movement of gelifluction. First, a rod was driven into the surface of the lobe. The rod should be perpendicular to the ground surface. As the gelifluction moves, the rod moves. Because the moving rate decreases from the surface downwards, the rod will dip downslope as it moves. Since it has been suggested that, at 70–100 cm below the surface, the moving rate of the active layer becomes negligible (Benedict, 1976), the dip angle can be used to measure the rate of surface gelifluction movement (see Figure 4).

The movement of the surface of the gelifluction lobe can be calculated as:

$$s = l \sin x \, (\sin (180^\circ - x - y))^{-1}$$

where s is the surface moving distance, l is the length of the rod (i.e. the rod's depth), x is the dip angle variation and y is the ground slope gradient.

The results of the measurement are shown in Table 3. The measurement at Laerdun Pass was set up on 7 August 1990 and remeasured on 24 August 1991 and 9 August 1992. The site at the head area of Urumqi River was set up on 17 August 1991 and remeasured on 1 August 1992.

The first year of data show that the surface movement at TLG is 6.28–17.8 cm; the mean is 14.46 cm. Two years' data show the surface movement to be 4.2–37.54 cm; the mean is 22.56 cm.

Figure 3 Gelifluction lobe at Laerdun Pass (2880 m ASL), which was excavated to investigate grain-size composition (< 2/mm) and water content (% weight) (see Table 2, Figure 4).

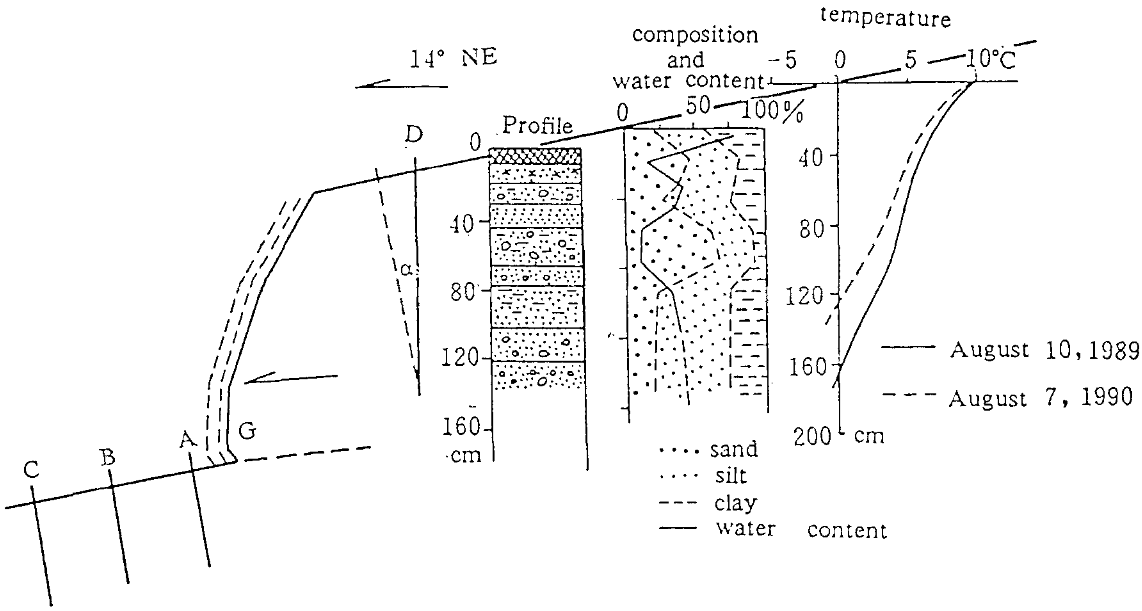

Figure 4 Stratigraphy, temperature, grain size and water content of the gelifluction lobe at Laerdun Pass (see Figure 3).

Table 2 The grain-size composition and water content within a gelifluction lobe at Laerdun Pass.

Horizon[1] (cm)	Sample depth (cm)	Grain size (%) Sand 2–0.05 mm	Silt 0.05–0.005 mm	Clay <0.005 mm	Water content (%)
0–9	4	–	–	–	75.21
15–20	5	45.88	37.50	16.61	16.61
20–33	13	39.31	42.30	18.39	37.12
33–45	12	27.08	50.61	22.31	33.46
45–65	20	62.12	29.24	8.64	9.98
65–77	12	67.40	25.20	7.40	9.71
77–101	24	23.11	51.67	25.22	33.12
101–125	24	22.35	51.87	25.78	33.49

[1] See soil profile in Figure 4.

The mean moving rate is 11.28 cm/a. The surface moving distance at NG is 7.7–13.5 cm, with a mean of 11.2 cm from 1991 to 1992. Therefore, the surface moving rate of gelifluction in the alpine periglacial environment of Tianshan Mountains is 2.1–18.77 cm/a, with a mean between 11.2 and 11.28 cm/a.

Table 4 shows the results of the moving rates at Laerdun Pass (TLG). The method used was to insert rods in front of the gelifluction lobe and then to measure the distance between the front and the rod. Six gelifluction lobes were measured and three were observed with three rows of piles to reflect the middle and both sides of the lobe. A–G is the distance between the first rod A and the gelifluction G, while A–B and B–C are the distances between rods A and B, B and C, respectively. The data in Table 4 show that the mean advancing rate is 1.86 cm/a. The middle advances faster than the sides of the gelifluction lobes (mean −3.1 cm/a). On the sides, the mean is 0.83 cm/a. The negative rates at TLG-3 were caused by faster

Table 3 Mean annual rates of surface movement of gelifluction, Tianshan Mountains, China.

	Site	Rod length (cm)	Dip angle 1	Dip angle 2	Dip angle 3	Moving distance 1 (cm)	Moving distance 2 (cm)	Mean annual rate (cm/a)
Laerdun Pass			8 August 1990	24 August 1991	9 August 1992			
	TLG-1	120	85°	77°	73°	16.8	25.08	12.54
	TLG-2	120	84°	77°	73°	14.7	23	11.5
	TLG-3	120	85°	82°	85°	6.28	4.2	2.1
	TLG-4	120	85°	77.5°	73.5°	16.7	23	11.5
	TLG-5	120	85°	76.5°	67°	17.8	37.54	18.77
Head area,			17 August 1991	1 August 1992				12.5
Urumqi	NL-1	110	90°	83.5°		12.5		13.5
River	NL-2	110	90°	83°		13.5		7.7
	NL-3	110	90°	86.5°		7.7		

ground creep rate in front of the gelifluction. This suggests that TLG-3 was inactive.

The distance changes among A, B and C reflect the moving of the active layer on which the gelifluction has developed. The data in Table 4 show both contraction and expansion of the active layer; there are 18 contraction observations, 20 expansion observations and 9 stable observations.

DISCUSSION AND CONCLUSION

Gelifluction occurs at 2500–3600 m ASL on north-facing slopes in the Tianshan Mountains. Most gelifluction is on slopes 10–30° in angle. They can be divided by length to width ratio into lobate forms with a ratio less than 1 and tongue forms with a ratio greater than 1. Most are of lobate form. The lengths of the gelifluction features range between 7 and 28.4 m, the widths between 6 and 30 m, and the heights 0.7 and 4 m.

Gelifluction is under the influence of gravity and frost action which cause slow mass movement downslope. Frost action causes sorting, stratification and tilting of pebbles. The moisture content relates to the stratification of grain size. The two-sided freezing and stratification of moisture leads to ice lenses paralleling the surface at the top of the permafrost (Cheng, 1983; Mackay, 1983). A sliding plane is provided as this ice melts, while the permafrost prohibits infiltration so that the active layer is easily saturated. The favoured grain-size composition for gelifluction is fine sand and silt, which can hold moisture and has low cohesive force.

The mean surface moving rate of the gelifluction is 11.14 cm/a. The fronts advance at a mean rate of 1.86 cm/a. Movement is greater in the middle than at the two sides.

It is difficult to exclude the effects of frost creep as we discuss gelifluction. The frost creep is 1.13 cm/a at the surface on a south-facing slope between 3460 and 3540 m ASL at the head area of Urumqi River (Cui *et al.*, 1993). Compared with the surface movement rate for gelifluction the creep rate of the active layer is much slower. The data on surface moving rate of gelifluction in periglacial environments all over the world show that the general moving rate is 0.5–10 cm/a (Dyke and Zoltai, 1980; Egginton and French, 1985; French, 1974). The faster moving rate in the Tianshan Mountains is because (1) the slope gradient is higher, (2) frequent freeze–thaw cycles occur, (3) favourable soil and moisture conditions are present.

The Daxigou Meteorological Station, which is at 3545 m ASL in the head area of Urumqi River, indicates that there are 100–130 days when the temperature fluctuates above and below 0°C. It is also estimated that the annual mean temperature is −3.0°C and precipitation is 850 mm at Laerdun Pass, using data from the Snow Avalanche Research Station (1776 m ASL). There is no direct relation between the moving rate of gelifluction and climate. Soil moisure plays a very important role in the movement of gelifluction.

ACKNOWLEDGEMENTS

The authors thank Professor H. M. French, Editor-in-Chief, for undertaking editorial revision and text improvement.

Table 4 Mean rates of gelifluction lobe movement, Laerdun Pass, Tianshan Mountains, China.

Site	Original distance (cm) 8 August 1990	Distance one year later (cm) 24 August 1991	Distance two years later (cm) 9 August 1992	Moving distance one year later (cm)	Moving distance two years later (cm)	Mean Rate (cm/a)
1 AL–G	12	10.9	8.5	1.1	2.4	1.75
A1–B1	50.8	53.2	53.2	−2.4	−0.3	−1.35
B1–C1	52.9	51.5	52	1.4	−0.5	0.45
A2–G	7	0	−3.5	7	3.5	5.25
A2–B2	54.9	56	54	−1.1	2	0.45
B2–C2	49.8	49.8	50.5	0	−0.7	−0.35
A3–G	1.5	0.5	−1.5	1	2	1.5
A3–B3	53.5	53.2	52.5	0.3	0.7	0.5
B3–C3	53.2	53	53.5	0.2	−0.5	−0.15
2 A1–G	4.5	4	5	0.5	−1	−0.25
A1–Bl	57.8	57	56	0.8	1	0.9
B1–C1	53	52.5	52	0.5	0.5	0.5
A2–G	6.5	5.8	5	0.7	0.8	0.75
A2–B2	55.3	55.7	55.5	−0.4	0.2	−0.1
B2–C2	53	52	52	1	0	0.5
A3–G	9	9.5	9	−0.5	0.5	0
A3–B3	55.2	56.5	56.5	−1.3	0	−0.65
B3–C3	51.6	49.8	49.5	1.8	0.3	1.05
3 A1–G	1	3.7	1	−2.7	2.7	0
A1–B1	48.6	48.5	48.8	0.1	−0.3	−0.1
B1–C1	82.4	88	87.5	−5.6	0.5	−2.55
A2–G	3.5	5.5	10	−2	−4.5	−3.25
A2–B2	57.5	56.2	56	1.3	0.2	0.75
B2–C2	52.5	52.5	54	0	−1.5	−0.75
A3–G	2	2	−1	0	3	1.5
A3–B3	50	50	50	0	0	0
B3–C3	51	51.5	51.5	−0.5	0	−0.25
4 A–G	2.75	1	0.5	1.75	0.5	1.25
A–B	65	65.8	66	−0.8	−0.2	−0.5
B–C	68	67.5	67.5	0.5	0	0.25
5 A–G	4.5	3.5	4.5	−1	1	0
A–B	56.3	55.8	55	0.5	0.8	0.65
B–C	47	47	47.5	0	−0.5	−0.25
6 A–G	12.5	0	–	12.5	1	0.75
A–B	108	109	110.5	−1	−1.5	−1.25

REFERENCES

Benedict, J. B. (1976). Frost creep and gelifluction features: a review. *Quaternary Research*, **2**, 165–226.

Cheng Guodong (1983). The mechanism of repeated segregation for the formation of thick layered ground ice. *Cold Regions Science and Technology*, **8**, 57–66.

Cui Zhijiu, Xiong Heigang and Liu Gengnian (1993). Observations on periglacial mass movement in the Head Area of Urumqi River and Laerdun Pass, Tianshan Mountains (in Chinese). *Journal of Glaciology and Geocryology*, **15**, 199–206.

Dyke, A. S. and Zoltai, S. C. (1980). Radiocarbon-dated mudboils, central Canadian Arctic. *Geological Survey of Canada*, Paper 80–1B, 271–275.

Egginton, P. A. and French, H. M. (1985). Solifluction and related processes, eastern Banks Island, N.W.T. *Canadian Journal of Earth Sciences*, **22**, 1671–1678.

French, H. M. (1974). Mass wasting at Sachs Harbour, Banks Island, N.W.T., Canada. *Arctic and Alpine Research*, **6**, 71–78.

Mackay, J. R. (1983). Downward water movement into frozen ground, western arctic coast, Canada. *Canadian Journal of Earth Sciences*, **20**, 120–134.

Yang Xinyuan (1990). *The Annual Report of Tianshan Glacial Observation Station* (in Chinese). Vol. 9, 43–59.