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Particle composition of glacial deposits in the West Kunlun Mountains

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Abstract

Characteristics of grain-size distribution of glacial tills taken from the West Kunlun Mountains, western China, are analyzed and their depositional environments are discussed. In grain size composition gravel and sand are dominant. Shapes of the cumulative curves of tills are different from non-glacial deposits. Grain size distribution of superglacial, englacial and lateral moraine tills has linear relation on the Rosin-Rammler Law probability diagram, while terminal, meltout and basal tills deviate obviously from it. The first peak on the frequency curves of grain size distribution of tills occurs in position of gravel grain (-3 – -4ϕ) while the second peak is lower in the position of silt (4–6ϕ). Obvious difference has been observed for the mean size (M_z) various types of tills. The standard deviation (σ_1) of tills are above 4.0ϕ, while the non-glacial deposits are less than 2.5ϕ. The skewness (Sk_1) of tills have positive values. The kurtosis (Kg) of tills are less than 1.00 while non-glacial deposits are generally more than 1.00. These grain size indicators including Matrix index and Abrasion index are very helpful to distinguish the depositional environments of tills.

1. Introduction

Particle compositions of sediments are presented from the results of particle analysis which are mainly shown as cumulative curves, frequency curves, histograms of grain size distribution and other parameters. These results can be used as environmental indicators and evidence of origin of the sediments. During the last two decades, a number of grain size data of tills have been accumulated based on studies of tills using advanced sedimentological methods, which reveal the relationship between subenvironments and particle features of glacial deposits, and provide a basis for classification of origin and landforms of glacial deposits (Sheeps, 1953; Landim and Frakes, 1968; Boulton, 1978; Ma, 1980; Haldorsen, 1981; Wang and Zhang 1981; Wu 1983; Zhang 1983; Li *et al.*, 1986). It is proved that the grain size of tills is not only important for identifying the subenvironment of glacial deposition, but also gives a qualitative or quantitative index for classification of glacial environments.

2. Sampling and laboratory analysis

During the fieldworks in the West Kunlun Mountains (35°00'–36°20'N and 80°30'–81°38'E), samples have been taken in different parts of modern moraines and sections of old moraines. In general, the coarse limit of sediments is fixed at 2 mm (-1ϕ) in laboratories in China. In order to check the distribution of coarser grains, grains smaller than 32 mm (-5ϕ) were analyzed in this study. Each sample was separated into two parts: those having grain sizes of 32 mm-0.063 mm (-5–4ϕ) were analyzed by wet siving, with an interval of 1/2ϕ; those having grain sizes less than 0.063 mm (4ϕ) were analyzed by pipette method with an interval of 1ϕ. It is quite clear that the curve shapes and size parameters are determined by the coarse limit (Wang and Zhang, 1981). Therefore, it is necessary to use equal upper limit of grains when we compare one group of samples to another.

Table 1. Grain size composition of glacial deposits and other deposits.

	Type of deposit	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
Modern tills	Englacial till	63.14	29.20	7.66	
	Superglacial till	45.83	37.52	10.80	5.85
	Meltout till	36.96	33.18	20.02	9.85
	Basal till	30.35	29.13	23.58	17.32
	Terminal moraine till	46.14	34.53	9.11	10.22
	Lateral moraine till	64.02	34.19	1.79	
Older tills	Terminal moraine till	35.47	41.42	14.77	8.34
	Terminal moraine till	50.72	33.48	10.15	5.65
	Terminal moraine till	39.98	33.24	16.11	10.74
	Lateral moraine till	51.61	32.32	11.46	4.61
	Basal till	29.13	34.10	18.88	17.89
Non-glacial deposits	Esker	6.40	86.04	3.32	4.24
	Glacio-fluvial	45.30	53.38	1.32	
	Aeolian	4.79	95.21	0	0
	Fluvial	65.24	23.10	10.66	0.97

3. Grain size characteristics of tills

3.1. Particle composition

The range of grain size of the tills is widespread, covering nearly all grain sizes, from boulders to fine clay, but the coarse particle size is dominant (Table 1). In the composition of matrix material (sand, silt, and clay), the sand content (-1−4ϕ) is 30−40%, silt (5−8ϕ) 10−20%, and clay (8ϕ) 5−18%. The differences between various types and ages of tills are distinguished from the distribution of grain size of tills. For example, the contents of sands and gravels are highest in englacial, superglacial and lateral moraine tills, lower in meltout and terminal moraine tills, and lowest in basal tills. On the contrary, the content of silt and clay is just the opposite. This means that the process of deposition is obviously controlled by the way of transportation and deposit medium.

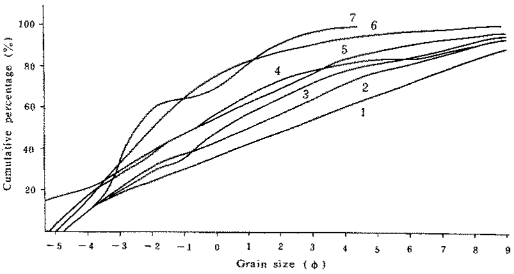

Fig. 1a. Grain-size cumulative curve of modern glacial deposits. 1: Basal till, 2: Meltout till, 3: Terminal moraine till, 4: Terminal moraine till, 5: Superglacial till, 6: Englacial till, 7: Lateral moraine till.

3.2. Grain size curves

3.2.1. Cumulative curves Cumulative plot is the most common way to illustrate the features of grain size. It can not only directly represent the range of grain size distributions, grading compositions and sorting degrees of sediments, but also permits cumulative percentages to be obtained from cumulative curves as well; from these the grain size parameters can be computed. The cumulative curves of the tills in this region are flat and widespread, and the grade ranges are from 32 mm to less than 0.002 mm (-5−9ϕ), which is obviously different from non-glacial deposits in Tables 1 and 2 (Fig. 1a, b). Different types of tills have different shapes of grain size cumulative curves. For example, the coarse particle fractions in lateral moraine till, superglacial till and englacial till are much higher, being located on the upper part of the diagram: on the contrary, meltout tills and basal tills are located on the middle and lower parts of the diagram, respectively, due to the gradual increase of fine particle fractions.

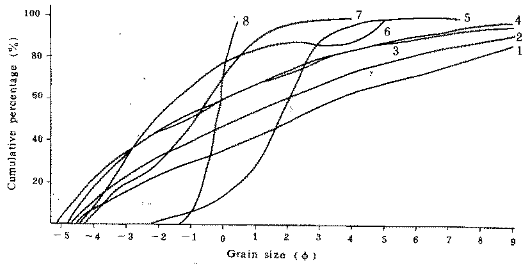

Fig. 1b. Grain-size cumulative curve of older tills and non-glacial deposits. 1: Basal till, 2: Terminal moraine till, 3: Terminal moraine till, 4: Lateral moraine till, 5: Fluvial sediments, 6: Esker sediments, 7: Glacio-fluvial sediments, 8: Aeolian sediments.

3.2.2. Probability curves of Rosin-Rammler Law of tills The particle distributions of clastic rocks broken by physical weathering or mechanical crushing observe the non-normal distribution of the Rosin-Rammler Law. For example, the particle compositions of industrial smashed debris (North Shanxi Research Team, Chengdu College of Geology, 1976), man-made crushed coal and feldspar debris (Wang and Zhang, 1981), typical prime till (Mu, 1985), superglacial debris, englacial debris and avalanche cone debris form a straight line on the Rosin—Rammler probability graph. Grain size analysis of tills in this region shows that coarse and medium fractions superglacial, englacial, and lateral moraine tills follow Rosin's distribution (Fig. 2a, b). In general, the coarse fractions of tills have only been mechanically crushed by ice, but under transportation over a long distance and strong abrasion, the coarse debris is gradually ground into fine fractions, therefore, the coarse fractions of glacial deposits follow the Rosin-Rammler Law, but the fine-grain fractions separate from the Rosin's distribution.

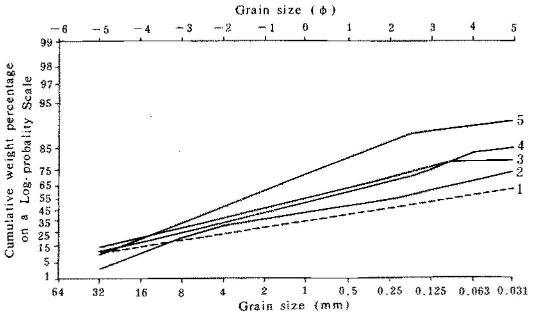

Fig. 2a. Grain-size Rosin-Rammler Law curve of modern glacial deposits. 1: Basal till, 2: Meltout till, 3: Terminal moraine till, 4: Superglacial till, 5: Englacial till.

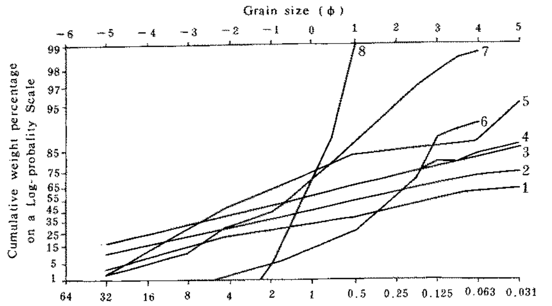

Fig. 2b. Grain-size Rosin-Rammler Law curve of older tills and non-glacial deposits. 1: Basal till, 2: Terminal moraine till, 3: Lateral moraine till, 4: Terminal moraine till, 5: Fluvial sediments, 6: Esker sediments, 7: Glacio-fluvial sediments, 8: Aeolian sediments.

3.2.3. Frequency curves In general, frequency curves of tills are bimodal or polymodal. All the frequency curves of tills in this region are polymodal. The coarse—fraction peak (first mode) is dominant: it is generally at the position of gravel grain (-4— -1ϕ), with only a few at the coarse—medium sand position (0ϕ). The second mode is lower and at the position of coarse-medium silt (4—6ϕ) (Fig. 3a—d). The results are similar to those in other regions in China and abroad. Haldorsen (1981) pointed out that the limit between matrix and debris of sediments lies at -1ϕ. Under crushing and abrasion, three clastic fractions are obtained, *i.e.* polymineral debris (-6— -1ϕ), single mineral grains (-1—6.5ϕ) and abrasion part (6.5—9ϕ). Thus the mode of -4— -1ϕ of grain size frequency curves of tills is in the range of polymineral debris, while the 4—6ϕ mode is in the range of single mineral composition. There is a limiting size range for each individual mineral, and the limiting size range of each mineral is different. The limited size ranges of igneous and metamorphic rocks are larger than those of sedimentary rocks, and the limited range of some soft rocks are even smaller in clay grain size. For most minerals in a limited size range, the peaks are concentrated in the 4—6ϕ range.

3.3. Grain size parameter and matrix and ablation index

3.3.1. Grain size parameter The main grain size parameters are Mean size (M_z), Inclusive Graphic Standard Deviation (σ_1), Inclusive Graphic Skewness (Sk_1) and Graphic Kurtosis (Kg). M_z indicates the mean grain size of the sediments, *i.e.* the amount of energy consumed in the process of deposition. σ_1 represents sorting of the sediments: smaller the value of σ_1 the better the sorting. Sk_1 represents the asymmetry of the peak in the frequency curves. When $Sk_1=0$, the peak is symmetry; when $Sk_1>0$, the grain size is concentrated in the coarse fraction, and the skewness curve is positive; when $Sk_1>0$, the grain size is concentrated in the fine fraction and the skewness curve is negative. Kg represents the ratio of sorting coefficients at tail and middle of the curve, which determines the convexity of the curve peak; when $Kg=1$, the curve is a normal distribution, when $Kg>1$ or $Kg<1$, the curve peak is sharp or flat respectively.

The calculated results of grain size parameter of tills in the region are shown in Table 2. They show that the mean sizes of glacial sediments and non-glacial sediments are mixed and widely spread. But

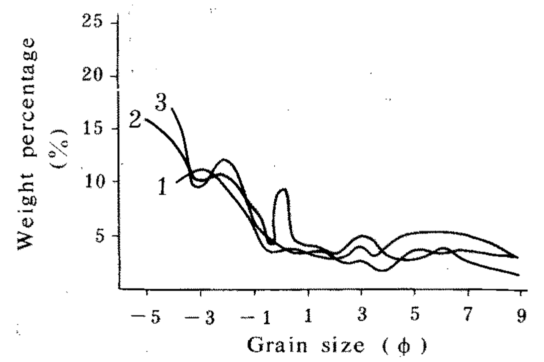

Fig. 3a. Grain-size frequency curve of modern glacial deposits (1). 1: Meltout till, 2: Terminal moraine till, 3: Superglacial till.

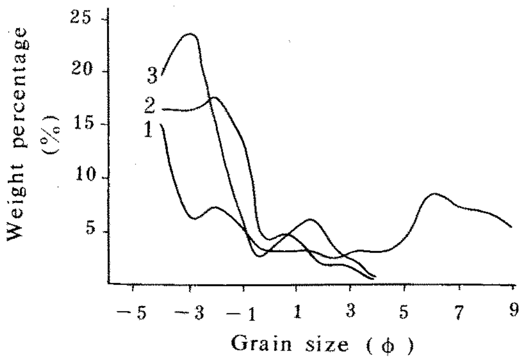

Fig. 3b. Grain-size frequency curve of modern glacial deposits (2). 1: Basal till, 2: Englacial till, 3: Lateral moraine till.

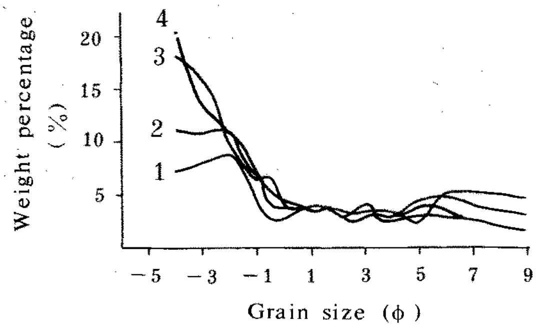

Fig. 3c. Grain-size frequency curve of older tills. 1: Basal till, 2: Terminal moraine till, 3: Terminal moraine till, 4: Lateral moraine till.

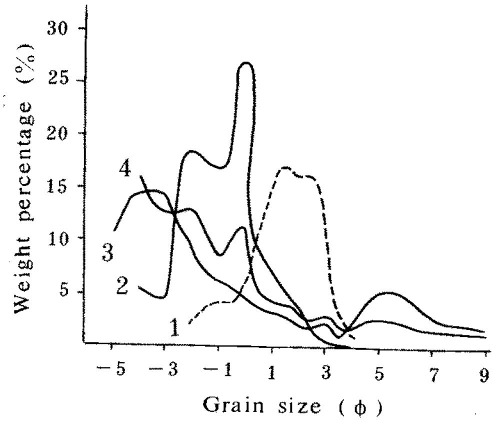

Fig. 3d. Grain-size frequency curve of glacial and non-glacial deposits. 1: Esker sediments, 2: Glacio-fluvial sediments, 3: Terminal moraine till, 4: Terminal moraine till.

Table 2. Grain size parameters of glacial tills and non-glacial deposits.

Type of deposit		Mean size (M_z:ϕ)	Standerd Deviation (σ_I:ϕ)	Skewness (Sk_I)	Kurtosis (K_G)	Matrix index	Abrasion index
Modern tills	Englacial till	−1.53	2.82	0.29	1.14	0.58	0.26
	Superglacial till	−0.53	4.24	0.46	0.95	1.05	0.29
	Meltout till	1.25	4.63	0.26	0.84	1.44	0.60
	Basal till	2.25	4.76	−0.05	0.80	1.74	0.81
	Terminal moraine till	1.09	4.25	0.23	0.86	0.95	0.26
	Lateral moraine till	−1.77	2.56	0.44	0.76	0.56	0.05
Older tills	Terminal moraine till	1.00	4.39	0.24	1.00	1.58	0.36
	Terminal moraine till	−0.62	4.04	0.50	0.91	0.86	0.30
	Terminal moraine till	1.11	4.54	0.27	0.87	1.24	0.49
	Lateral moraine till	−0.48	4.20	0.29	0.91	0.85	0.36
	Basal till	2.20	4.94	0.29	0.67	1.82	0.55
Non-glacical deposit	Esker	1.58	1.81	−0.02	1.62	13.96	0.04
	Glacio-fluvial	−0.87	1.72	−0.10	1.14	1.21	0.02
	Aeolian	0.17	0.26	−0.65	0.85	19.88	0
	Fluvial	−1.43	2.49	0.42	1.19	0.52	0.46

the difference between different types of tills are obvious. The mean size of basal tills, including the fine sands, meltout tills and terminal moraine tills, is medium sands, while the englacial tills, superglacial tills and lateral moraine tills vary from extreme coarse sands to fine gravels. But there is no obviously difference between tills of different ages. There is an obvious difference between sorting coefficients of glacial sediments and non-glacial deposits. Most tills have coefficients above 4.00ϕ, but the coefficients of non-glacial deposits are below 2.50ϕ; this means that the sorting of tills is poor. The values of skewness vary widely, from -0.02 to 0.50; skewness of tills is positive, except for modern basal tills, but the skewness of non-glacial deposits is negative, except for fluvial deposits. The difference of kurtosis between glacial sediment and non-glacial deposits is not very clear: in general, the kurtosis of tills is mostly below 1.00, but that of non–glacial deposits is above 1.00.

3.3.2. Matrix index and abrasion index These are used as indicators of abrasion level of tills, which is important for subclassification of tills and study of glacial sediments. The matrix index and the abrasion index are:

$$\text{Matrix Index}=\frac{\text{sand}+\text{silt}}{\text{gravel}};$$

$$\text{Abrasion Index}=\frac{\text{silt}}{\text{sand}}$$

The statistical results of matrix index and abrasion index of the sediments in this region are shown in Table 2. This shows the difference between the matrix index and abrasion index of tills and non-glacial sediments. The matrix and abrasion indices of modern tills are 0.56–1.74 and 0.26–0.81 respectively. The indices of non-glacial sediments (except fluvial deposits) are 1.21– 19.88 and 0–0.04 respectively. Both the matrix and abrasion indices of glacial sediments are highest in basal tills, median in meltout tills and end moraine tills and lowest in englacial tills, superglacial tills and lateral moraine tills. Comparison of all results in Table 2 shows that different transport media caused different types of abrasion. Under an ice medium, the abrasion is different in different transported zones. In fact, the longer the distance of transportation, the longer the abrasion index.

4. Characteristics of grain size of glacial sediments, and its environmental importance

Grain size data of sediments can be used to distinguish environments in which the sediments are deposited, such as aeolian, fluvial, lacustrine, marine, muddy stream deposits, and igneous clastics (*e.g.* Mu, 1985). Similarly, the grain size characteristics of tills can also be used as indicators to judge the subenvironments. In recent years, some environmental or subenvironmental indicators on plotted diagrams of grain size parameters have been worked out based on particle analysis of modern sediments, the environments of which are known. It has been proved that the diagram is successful in determining paleoenvironments of sediments. The grain size parameters (M_z, σ_1, Sk_1, Kg, Matrix index and Abrasion index) (Fig. 4a–e) in the West Kunlun Mountains have been plotted on the diagram. It is quite clear that the boundary between glacial sediments and non–glacial sediments on the diagram is distinct; even subenvironments of glacial sediments can be classified on the plotted diagrams. Among the subenvironment of glacial sediments, basal tills are significant and occupy a certain position on the plotted diagram, which is identical with Mills' (1977) results in valley glacial sediment. Basal tills of valley glaciers are significant indicators of glacial crushing and abrasion in the process of transportation and deposition under an ice medium.

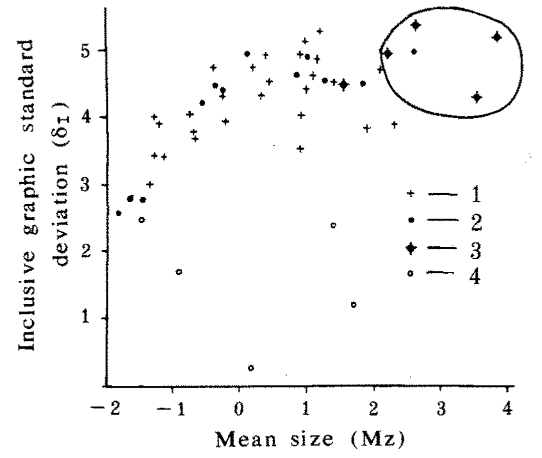

Fig. 4a. Plots of mean size versus inclusive graphic standard deviation. 1: Older till, 2: Modern till, 3: Basal till, 4: Non-glacial deposits.

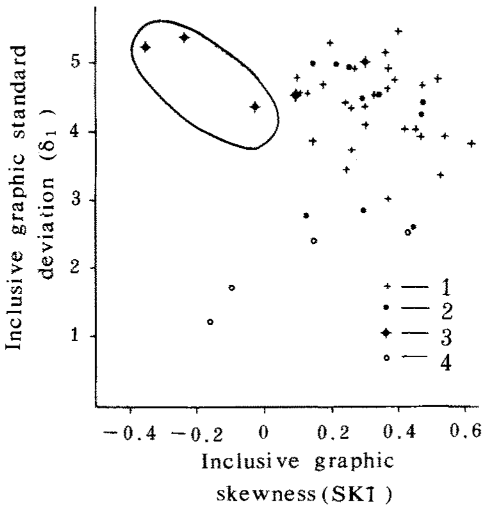

Fig. 4b. Plots of inclusive graphic skewness versus inclusive graphic standard deviation. 1: Older till, 2: Modern till, 3: Basal till, 4: Non-glacial deposits.

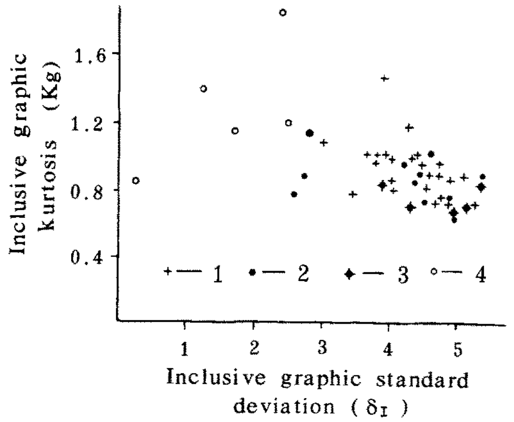

Fig. 4c. Plots of inclusive graphic standard deviation versus inclusive graphic kurtosis. 1: Older till, 2: Modern till, 3: Basal till, 4: Non-glacial deposits.

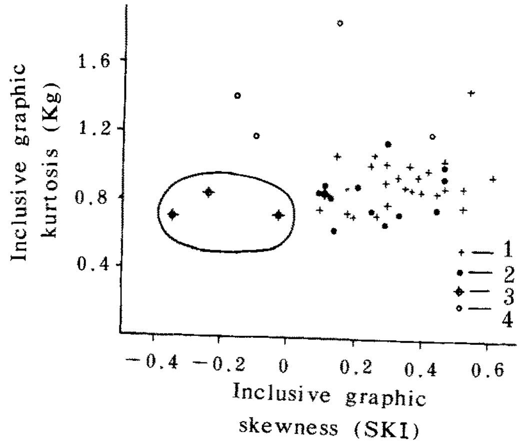

Fig. 4d. Plots of inclusive graphic skewness versus inclusive graphic kurtosis. 1: Older till, 2: Modern till, 3: Basal till, 4: Non-glacial deposits.

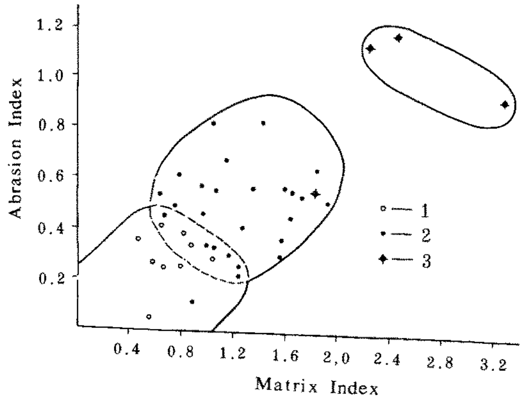

Fig. 4e. Plots of matrix index versus abrasion index of tills. 1: Older till, 2: Modern till, 3: Basal till, 4: Non-glacial depsits.

5. Conclusions

The grain size characteristics of glacial sediments in the West Kunlun Mountains are obviously significant. The difference between grain size characteristics (grain grading composition, grain size distribution curves and grain size parameters) of glacial and non-glacial sediments are distinct. Grain size characteristics of different types and ages of tills have different features too. This means that the glacial sediments have undergone different crushing and abrasion in different transportation zones under ice media, which formed different grain size distributions. Tills of different ages have similar grain size distributions because the transportation medium and deposition process are similar.

Modes -4— -1ϕ and 4—6ϕ on the frequency curves of tills in the study region reflect specific transportational and depositional environments by glaciers in which mechanical crushing and abrasion are dominant.

The diagrams of grain size parameters are not only successful in distinguishing glacial sediments and other sediments, but also subenvironments of glacial deposits. But, the plotted diagrams of Matrix index and Abrasion index are more useful in judging glacial deposit subenvironments.

References

Boulton, G. S. (1978): Boulder shapes and grain—size distribution of debris as indicators of transport paths through a glacier and till genesis. Sedimentology, **25**, 773—799.

Haldorsen, S. (1981): Grain—size distribution of subglacial till and its relation to glacial crushing and abrasion. Boreas, **10**, 91—105.

Landim, P.M. and Frakes, L.A. (1968): Distinction between tills and other diamicton based on textural characteristics. Jour. Sed. Petrol., **38**, (4).

Li, J., Zheng, B., Yang, X., Xie, Y., Zhang, L., Ma, Z., and Xu, S. (1986): Glaciers of Xizang (Tibet), Beijing, Science Press, 328p. (in Chinese).

Ma, C. (1980): Preliminary analysis of grain size of moraines in Tianshan and Qingzang Plateau. Journal of Glaciology and Cryopedology, **2** Special Issue, 80—86. (in Chinese)

Mu, Y. (1985): Nonglacial genesis of boulder clay in Lushan. Symposium of National Conference on Quaternary Glacier and Periglacial, Beijing, Science Press, 66—70 (in Chinese).

Mills, H. H. (1977): Textural characteristics of drift from some representative cordilleran glacier. Geol. Soci. Amer., Bull., **88**, (7).

North Shanxi Research Team, Chengdu College of Geology (1976): Grain-size analysis of sedimentary rock (sediments) and their apply, Geology Press, 39—44.

Sheeps, V. C. (1953): Correlation of the tills of northeastern Ohio by size analysis. Jour. Sed. Petrol. **23**, (1).

Wang, J. and Zhang, Z. (1981): Particle size analysis of tills at the head of Urumqi river. Journal of Glaciology and Cryopedology, **3** Special Issue, 64—77 (in Chinese).

Wu, A. (1983): The characteristics of grain-size parameters of till and their relation to sedimentary environments. Journal of Glaciology and Cryopedology, **5**, (2), 47—53 (in Chinese).

Zhang, Z. (1983): Grain-size characteristics of moraines in the region of Mt. Bogda. Journal of Glaciology and Cryopedology, **5**, (3), 191—200 (in Chinese).