Chinese Journal of Polar Science, Vol. 8, No. 2, 111 - 120, December 1997

Grain size characteristics and environmental indication of the sediments around Great Wall Station, Antarctica*

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Received May 15, 1997

Abstract The Great Wall Station of China (62°13′S, 58°58′W) is located at the Fildes Peninsula of King George Island, South Shetland Islands, Antarctica. Sediments in the area can be divided into glacial, periglacial, fluvial lacustrine and littoral deposits in origin. Analysis of the fine particals (below 3.52 mm) shows obviously difference among grain size composition, frequency curve, accumulative curve and scatter diagram. In order of periglacial-glacial-fluvial-littoral deposit, sand increases, silt and clay decreases; sorting changes from poor to good; mean grain size is at very fine-fine-medium-coarse sand respectively; skewness changes from very positive to near symmetric. Scatter diagram of grain size parameters shows difference in the sediments. Variation among frequency curves reflects processing and forming condition of the sediments. The fluvial and littoral deposits follow normal distribution, they are straight lines in normal accumulative diagram. The glacial and periglacial deposits follow Rosin's distribution, they are straight lines in Rosin's accumulative diagram.
Key words grain size, deposit, environment, Antarctica.

1 Introduction

The Great Wall Station of China (62°12′24″S, 58°57′52″W) is located at the Fildes Peninsula of King George Island, South Shetland Islands, Antarctica. Field work areas include the ice-free area of the Fildes Peninsula and the Nelson Island. The bedrock is basalt belonging to Late Cretaceous and Early Tertiary (Li and Liu 1987). Landforms include ice caps, periglacial forms, river, lake and coastal forms (Xie *et al.* 1993). Summer high temperature is 11.7℃ and winter low temperature is −26.6℃. Mean annual temperature is −2.6℃. Mean annual precipitation is 415 mm. Thickness of permafrost is 30 - 50 m with 0.35 - 1.20 m active layer.

Tills are distributed along the magin of Kolins Ice Cap and Nelson Ice Cap. Melt-out till is the major type in this area. Flow till and shear till were noticed at the mar-

* This project was supported by the National Natural Science Foundation of China.

gin of Kolins Ice Cap. Glaciation is one of the most important agents to produce sediment on ground surface in Antarctica. In ice-free area, till can be found anywhere, however, tills are undergoing frost action, fluvial and wave actions. Periglacial deposit refers to sediment formed by frost action, and pre-sediment reworked by periglacial process, such as patterned ground, gelifluction, rockglacier, talus, and so on (Cui *et al.* 1989; Liu 1991; Xie *et al.* 1993). Periglacial deposit covers large area of the researched area, the thickness varies greatly in defferent position. Fluvial deposit refers to running water reformed till and periglacial deposit. The rivers are seasonal and flow only for a short distance in this area. Discharge and velocity change enormously, flood occurs in January and February as snow and ice melt. The deposit undergoes limited transformation. Littoral deposit includes beach gravel and beach sand. The deposit underwent the action of wave, tide and floating ice. Samples are taken from beach sand only, because of the technic reason. Composition of beach sand could reflect local coast dynamics. The fragments come from till, periglacial and fluvial deposits, small part is produced by wave action (Liu and Cui 1990).

2 Sampling description

The deposits around the Great Wall Station of China can be divided into glacial, periglacial, fluvial, lacustrine, and littoral deposits. The lacustrine deposit was researched by Xie *et al.* (1990, 1993), therefore, this paper will not discuss it again.

Modern moraines are distributed along the margins of Kolins Ice Cap and Nelson Ice Cap. In ice free area, tills are scattered on ground as the residuals of retreating ice after Last Glaciation. Till samples were collected from modern moraines on Kolins Ice Cap and Nelson Ice Cap.

Most of ice free area near Great Wall Station are bedrock hill and weathering mantle landform, sometimes weathering mantle with till covers ground. Frost action and weak chemical weathering lead to fining and sorting of the sediments (Liu 1991). Periglacial deposit is clearly worked by freeze-thaw action. Samples were taken from patterned ground about 30 m above sea level near Great Wall Station.

Samples of fluvial deposit were collected on the north of Great Wall Station, 10 – 14 m above sea level. Samples of littoral deposit were collected from beachs around the Fildes Peninsula and the Nelson Island.

3 Grain size composition and parameters

Measurement was taken of the samples with the grain size smaller than 3.52 mm (−1.8φ), 15 size grades may be divided, and mean size grade is 0.78φ, minimum size 0.001 mm (10φ). Deposits with grain size 3.52 – 0.04 mm are sieved out, and those below 0.04 mm are measured by using photoelectric auto-analyser. It seems reasonable to measure the whole samples to realize the composition of the sediments. Nevertheless, measurement was made only on those with grain size below 3.52 mm. In consideration of the sediment composition, which contains information about its forming condition and process, the fine part (<3.52 mm) might carry valueable information also. This paper attempts to use grain size smaller than 3.52 mm to discuss environmental condition and charateristics of the deposits in the area around Great Wall Station of China, Antarctica.

3.1 *Grain size composition*

Sand beaches are composed of sand and a little silt. Gravel beaches are mainly composed of gravels with diameter of 3 - 5 cm on sedimentary coast or 15 - 20 cm in bedrock coast. The fine grain smaller than 3.52 mm is only a small part of the whole composition in glacial, periglacial and fluvial deposits. For example, the fine grain only occupies 20% - 30% of the total samples in melt-out till. But shear till and flow till are composed of sand and silt. In periglacial deposit, the fine grain usually accounts for 40% or more of the sample. In frost scattered sediment, the fine grain is only 5%, while in centre of patterned ground, the fine material is as high as 70% - 80%.

The grain size composition and parameter are listed in Table 1. It shows that in glacial deposit sand content is as high as 50.16% - 100% (mean 78.04%), silt content 0 - 46.06% (mean 14.64%), clay content 0 - 10.78% (mean 4.31%). In periglacial deposit, sand content is 44.65% - 86.25% (mean 62.41%), silt 9.58% - 44.53% (mean 27.65%), clay 4.17% - 16.68% (mean 9.94%). In fluvial deposit, sand content is 77.57% - 100% (mean 90.22%), silt 0 - 17.79% (mean 8.14%), clay 0 - 4.64% (mean 1.63%). In beach sand, the sediment is composed of 100% of sand. It is clear that, in order of periglacial-glacial-fluvial-littoral deposits, sand content increases, silt and clay contents decrease.

3.2 *Grain size parameters*

The grain size parameters include mean size, sorting coefficient, skewness and kurtosis. The results in Table 1 are based on the formulae by Folk (1966). The mean grain size (M_z) represents the centralization of grain distribution. The soting coefficient uses standard deviation (δ), as index. The skewness (SK_I) is a symmetry index to show the relation between middle size and mean size. The kurtosis (K_G) is an index of salience to the peak of frequence curve.

The data in Table 1 show that in glacial deposit mean size varies from 0.585 - 4.403φ, standard deviation varies from 1.146 - 3.708φ, skewness varies from 0.092 - 0.532 and kurtosis varies from 0.561 - 1.409. The total mean values of M_z, δ, SK_I and K_G are 2.121φ, 2.537φ, 0.293 and 0.909, respectively. The data indicate that the mean grain size of fine till is of fine sand grade, with poor sorting, positive skewness of frequency curve, and medium peak salience.

As to periglacial deposit, the mean grain size changes from 0.516 - 4.906φ, standard deviation from 2.236 - 3.783φ, skewness from −0.110 - 1.535, and kurtosis from 0.464 - 1.241. The total mean values of M_z, δ, SK_I and K_G are 3.209φ, 3.204φ, 0.302 and 0.769, respectively. The data indicate that the mean grain size of the fine periglacial deposit is of extremely fine sand grade, with poor sorting, extremely positive skewness of frequency curve, and broad peak salience.

Table 1. Grain size coposition and parameters (Folk, 1966)

Sample	Composition/%			Parameters (Folk)			
	Sand	Silt	Clay	M_z/φ	δ/φ	SK_I	K_G
NG-1	64.20	27.57	8.23	2.498	3.619	0.232	0.561
NG-2	57.57	31.65	10.78	2.986	3.708	0.092	0.634
NG-3	73.46	18.87	7.64	2.324	3.404	0.347	0.641
NG-4	87.58	10.82	1.60	1.365	2.157	0.387	1.409
NG-5	50.16	46.06	3.78	4.403	1.307	0.222	1.251
NG-6	100	0	0	2.741	1.146	0.079	0.576
NG-7	96.69	0.86	2.45	1.115	2.566	0.335	0.982
NG-8	83.88	13.69	2.43	1.073	2.671	0.532	0.979
NG-9	88.85	9.24	1.91	0.585	2.255	0.431	1.154
NP-1	68.32	22.40	9.28	3.250	3.197	0.310	0.804
NP-2	48.37	40.17	11.46	4.365	3.090	−0.110	0.878
NP-3	57.68	28.02	14.30	3.162	3.628	0.208	0.636
NP-4	66.67	25.60	7.73	2.828	3.460	0.118	0.659
NP-5	80.76	14.12	5.12	1.280	2.739	1.048	0.766
NP-6	86.25	9.58	4.17	0.516	2.236	1.535	1.241
NP-7	63.65	23.19	13.16	2.609	3.747	0.361	0.539
NP-8	71.17	22.00	6.83	2.041	3.313	0.793	0.464
NP-9	81.80	12.63	5.57	1.449	3.138	0.645	1.057
NP-10	63.09	25.14	11.77	2.709	3.649	0.295	0.546
NP-11	80.03	12.14	7.83	1.522	3.283	0.801	0.869
NP-12	56.12	35.89	7.99	4.062	2.929	0.057	0.953
NP-13	45.89	44.53	9.58	4.731	2.723	−0.040	1.238
NP-14	50.66	37.45	11.89	3.888	3.279	−0.100	0.870
NP-15	75.61	18.02	6.37	1.900	3.267	0.368	0.658
NP-16	62.96	26.22	10.82	2.857	3.657	0.140	0.545
NP-17	71.33	19.73	8.94	2.157	3.531	0.531	0.552
NP-18	45.44	44.14	10.42	4.888	2.427	−0.033	0.818
NP-19	44.65	42.51	12.84	4.906	2.521	−0.024	0.871
NP-20	48.44	41.20	10.36	4.621	2.927	−0.066	1.042
NP-21	54.61	31.86	13.53	3.107	3.783	0.025	0.507
NP-22	50.50	32.82	16.68	4.210	3.426	−0.014	0.856
NP-23	51.99	34.61	13.40	4.031	3.365	−0.038	0.884
NP-24	60.46	26.29	13.25	2.807	3.711	0.234	0.500
NP-25	73.85	21.05	5.10	1.824	3.084	0.688	0.528
NR-1	93.86	5.97	0.17	0.226	1.853	0.511	0.936
NR-2	100	0	0	0.589	1.291	−0.337	1.805
NR-3	77.57	17.79	4.64	3.320	2.060	0.343	1.466
NR-4	79.72	16.95	3.33	2.774	2.560	0.269	1.341
NR-5	100	0	0	1.566	0.667	0.094	1.502
NS-1	100	0	0	−0.273	0.823	0.340	1.749
NS-2	100	0	0	0.542	0.615	0.114	1.590
NS-3	100	0	0	−0.146	0.597	0.210	0.816
NS-4	100	0	0	1.519	0.933	−0.070	0.653
NS-5	100	0	0	0.630	1.204	0.112	2.925
NS-6	100	0	0	−0.481	0.734	0.397	0.379
NS-7	100	0	0	0.151	0.600	−0.199	0.805
NS-8	100	0	0	1.097	0.624	−0.193	0.778
NS-9	100	0	0	0.029	0.615	−0.054	0.739
NS-10	100	0	0	1.655	0.886	−0.090	0.829
NS-11	100	0	0	1.280	1.030	0.370	0.594
NS-12	100	0	0	1.391	0.463	−0.190	1.127
NS-13	100	0	0	−0.007	0.652	−0.088	0.747
NS-14	100	0	0	0.688	0.553	0.279	1.171
NS-15	100	0	0	1.178	0.739	0.404	1.344
NS-16	100	0	0	0.203	0.613	−0.238	0.879
NS-17	100	0	0	0.461	0.419	−0.152	1.060
NS-18	100	0	0	1.535	0.363	0.098	0.918
NS-19	100	0	0	1.527	0.602	−0.019	1.437
NS-20	100	0	0	1.250	0.677	−0.144	1.085
NS-21	100	0	0	1.436	0.457	−0.172	1.125
NS-22	100	0	0	1.480	0.794	−0.046	0.720
NS-23	100	0	0	−0.211	0.583	0.236	0.896
NS24	100	0	0	1.579	0.460	0.166	1.105

Mean grain size of fluvial deposit is between 0.226 – 3.320φ, standard deviation between 0. 667 – 2. 560φ, skewness between −0. 337 – 0. 511, and Kurtosis between 0. 936 – 1. 502. The total mean values of M_z, δ, SK_I and K_G are 1. 695φ, 1. 686φ, 0. 176 and 1. 226, respectively. The data indicate that the mean grain size of the fine fluvial deposit is of sand grade, with relative poor sorting, positive skewness of frequency curve and narrow peak salience.

Mean grain size of beach sand varies from −0. 481 – 1. 655φ, standard deviation from 0. 363 – 1. 030φ, skewness from −0. 404 – 0. 397, and kurtosis from 0. 397 – 2. 925. The total mean values of M_z, δ, SK_I and K_G are 0. 768φ, 0. 682φ, 0. 011 and 0. 992. The data indicate that the mean grain size of the beach sand is of coarse sand grade, with good sorting, nearly symmetry skewness of frequency curve and medium peak salience.

The total mean values are listed in Table 2. It can be seen that from periglacial to glacial to fluvial and to littoral deposits the grain size changes from extremely fine to coarse sand, sorting from poor to good, skewness from extremely positive to nearly symmetry, and peak salience from broad to medium, however, peak salience of fluvial is narrow.

Table 2. The total mean value of the grain size composition and parameters

	Composition/%			Parameters (Folk)			
	Sand	Silt	Clay	M_z/φ	δ/φ	SK_I	K_G
Periglacial	62. 41	27. 65	9. 94	3. 209	3. 204	0. 302	0. 769
Glacial	78. 04	17. 64	4. 31	2. 121	2. 537	0. 293	0. 909
Fluvial	90. 22	8. 14	1. 63	1. 695	1. 686	0. 176	1. 266
Littoral	100	0	0	0. 768	0. 682	0. 011	0. 992

3. 3 Grain size diagram

It is attempted to use scatter graph of the grain size parameters for differentiating the deposits. Although the sensitivity of scatter graph is in doult, researchers believe that is an useful supplementary method in environment reconstruction (North Shaanxi Team of Chengdu Geology College 1978; Xie *et al.* 1993).

The scatter diagrams of the deposits show obviously difference (Fig. 1). Fig. 1 (a, b, d) show that it is easy to differ beach sand from other deposit with M_z-δ diagram, SK_I-δ diagram and K_G-δ diagram. Glacial and periglacial deposits differ from beach sand easily, but difference between glacial and periglacial deposits is not so remarkable in Fig. 1. Dots of fluvial deposit is distributed between glacial-periglacial deposit and beach sand. The diagrams in Fig. 1 provide evidence that in sub-antarctic area the changes of mean grain size and standard deviation follow the order of periglacial, glacial, fluvial and littoral deposits.

In SK_I-M_z diagram (Fig. 1(c)), glacial and periglacial deposits show self-linear interrelation. Slope of regression line to periglacial deposit is steeper than that of glacial deposit, this reflects greater variation of skewness in periglacial deposit. The clear separation among littoral, fluvial and periglacial deposits in Fig. 1(a) shows that M_z and δ are useful to differ these sediments. Glacial deposit: $Y=0.898-0.214X$, $\gamma=0.80$. Periglacial deposit: $Y=1.169-0.286X$, $\gamma=0.91$. Where $Y=SK_I$, $X=M_z$, $\gamma=$ coefficient of interrelation.

Beach sand, glacial and periglacial deposits are separated in Fig. 1(b), that is to say, SK_I and δ are useful to differ these deposits. Fig. 1(d) indicates that K_G and δ are useful to differ beach sand, fluvial and periglacial deposits.

The above analysis indicates that scatter diagram of grain size parameters can be useful to differ various sediments, and comparison of different assemblage of the parameters can improve the precision of environmental interpretation.

4 Frequency curve and accumulation curve

4.1 Frequency curve

Grain size composition and frequency curve of the till reflect both the action between ice and bedrock, as well as the melt-out process. NG in Fig. 2 represents three typical glacial frequency curves. NG-1 and NG-5 are melt-out till with poor sorting (δ = 3.619, 3.708) and multimodal distribution (3 or 4 peaks). Meltout till NG-1 from Kolins Ice Cap has more silt than that NG-5 from Nelson Ice Cap which might reflect the greater abrasion under larger glacier of the former. In comparison, meltout till of Nelson Ice Cap is richer in sand than that of the Kolins Ice Cap. Flow-till NG-4 from Kolins Ice Cap shows a 35% peak in 4 – 5φ as shown in Fig. 2, with relatively poor sorting (δ = 1.365). Shear till NG-6 from Kolins shows two peaks, with median sorting (δ = 1.146).

Composition of the perigalcial deposit is complicated, it includes fragment by frost action and former deposit reformed by periglacial process. The samples were

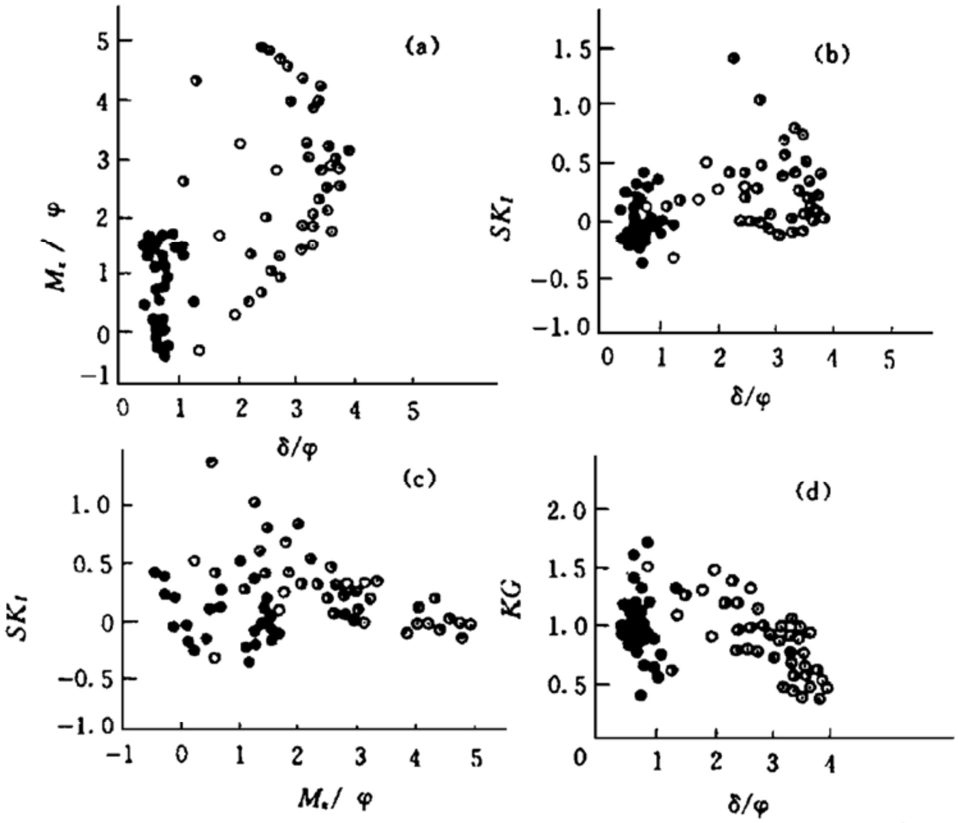

Fig. 1. Scatter diagram of the parameters (Folk). ◯: fluvial deposit; ◯: littoral deposit; ◯: glacial depoist; ◯: periglacial deposit.

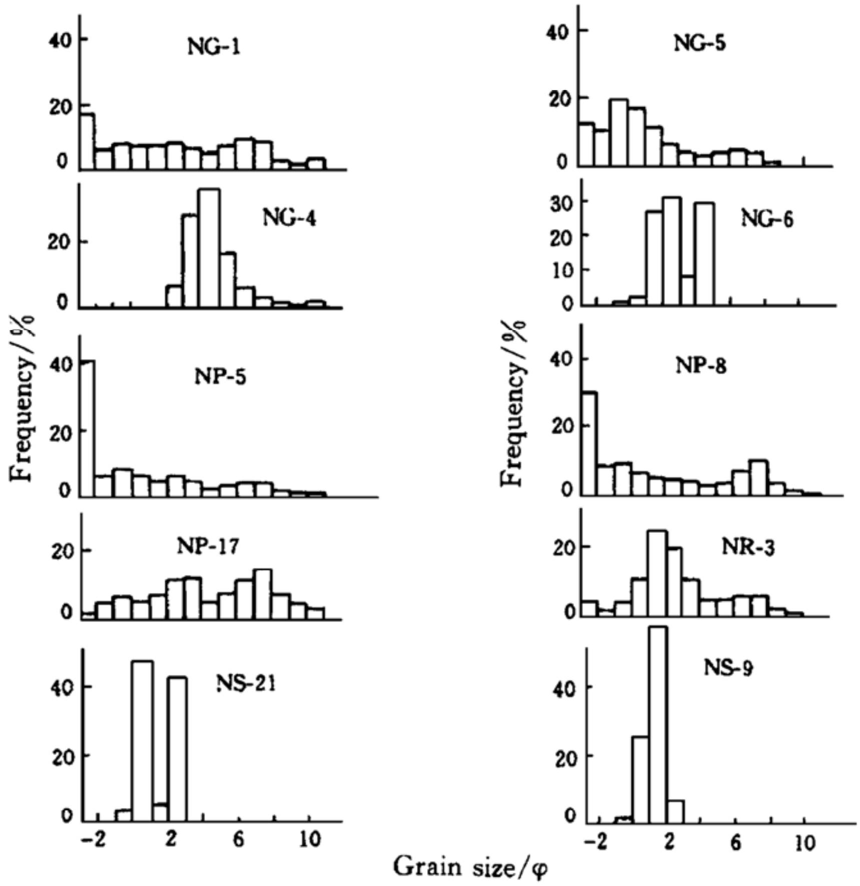

Fig. 2. Diagram displaying typical frequency curve. NG:glacial depoist; NP:periglacial deposit; NR: fluvial deposit; NS:littoral deposit.

collected at typical weathering mantle with patterned ground and at other periglacial sections(NP in Table 1 and Fig. 2). Samples from a profile of patterned ground show the vertical grain size coposition,NP-5 at the base of the profile 90 – 100 cm in depth is composed mainly gravel,coarse sand accounting for 40% of its material. NP-8 at the middle of profile 55 cm in depth shows an 11% peak in 7 – 8φ. NP-7 was taken from the centre of the sorted circle on top of the profile,the frequency curve shows a 12% peak in 3 – 4φ and a 15% peak in 7 – 8φ. The grain size composition and frequency curve support the view that fine partical are sorting upwards in active layer of periglacial environment.

Fluvial deposit NR-3 shows a 25% peak in 1 – 2φ in the frequency cueve of Fig. 2. Because of seasonal activity and short flow distance,influence of fluviation to sediment is limited in Antarctica. Frequency curves of beach sand demonstrate single and double peaks (NR in Fig. 2). Samples from lower tide beach show mostly double peaks,for example,NS-21 from lower tide beach of Nelson Island shows a 47.6% peak in 0 – 1φ and a 42.3% peak in 2 – 3φ. This is the result of double currents by wave on lower tide beach. Samples from higher tide beach show mostly single peak, for example,NS-9 from Biological Bay of Fildes Peninsula shows a 64% peak in 1 – 2φ. This reflects a single current of wave action on higher tide beach.

4.2 Analysis of the peak distribution in frequency curves

Fig. 3 shows the peak distribution of the deposits. Glacial deposit has four peaks generally, but the peaks are small and non-outstanding. Periglacial deposit has four peaks too, it differs from till by its richer fine tail and greater peak in 7 – 8φ. It is suggested that there exists further breaking process in periglacial environment. Fluvial deposit shows an evident peak in 1 – 2φ. This reflects well developed jumping load. Littoral deposit shows peak distribution in 0 – 1φ. This reflects good sorting and coarser grain size. In the comparison of Fig. 2 and Fig. 3, the typical grain size frequency curve for the glacial, periglacial, fluvial and littoral deposits are NG-1, NP-8, NR-3 and NS-9, respectively.

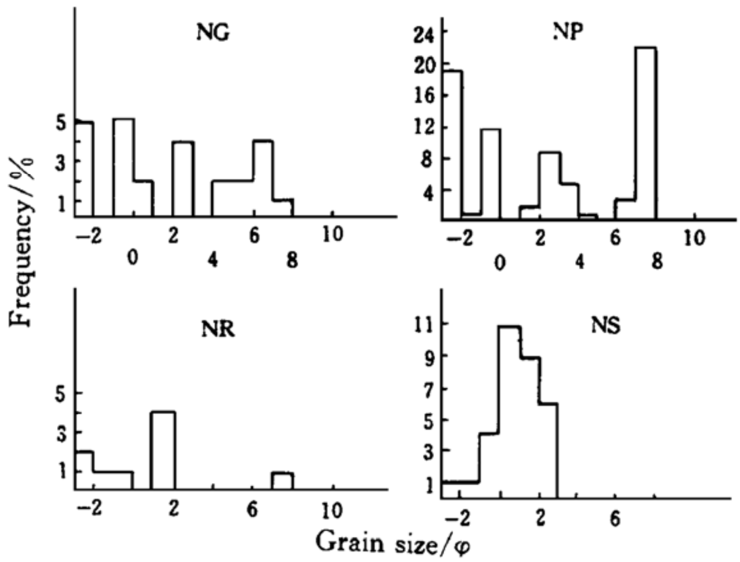

Fig. 3. Peak distribution of the deposits. NG: glacial deposit; NP: periglacial deposit; NR: fluvial deposit; NS: littoral deposit.

4. 3 Accumulative curve

The littoral and fluvial deposits present single line or broken line in normal accumulative diagram (NS and NR in Fig. 4), they follow normal distribution (Visher 1969). Glacial and periglacial deposits present up-towering curve in normal accumulative diagram, but they are single line or broken line in Rosin's accumulative diagram (NG and NP in Fig. 4) and follow Rosin distribution (Rosin and Mammler 1933; Kittleman 1964; Wang and Zhang 1981).

The fluvial deposit shows three or four broken line in normal accumulative diagram (NR in Fig. 4), the three loads (traction, saltation and suspended) are expressed in the diagram, some samples appear two saltation loads.

The glacial deposit and periglacial deposit are drawn in Rosin's accumulative diagram (NG and NP in Fig. 4). Shear till is single line and meltout till is two or three broken line. The single line of shear till reflects its monogenetic process of fragmentation in shear zone, while the broken line of meltout till reflects complex processes during melting of glacier. The periglacial deposit shows two and three broken line with a tidy straight tail line behind 6 – 7φ (NP in Fig. 4). The broken line also reflects complex periglacial processes, while the well developed fine tail resulted from frost weathering.

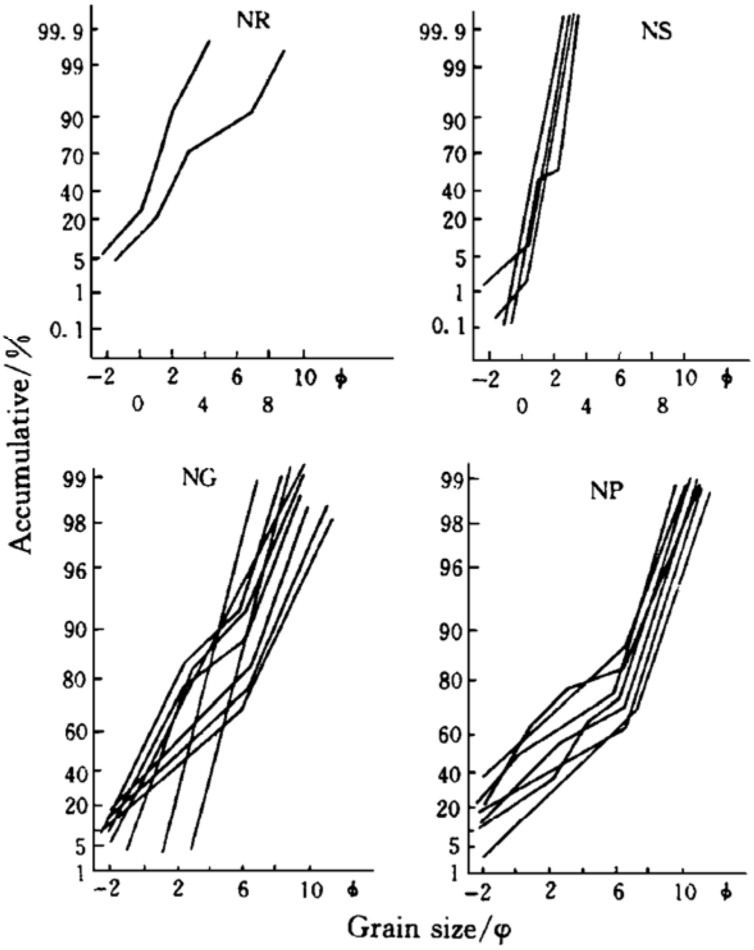

Fig. 4. Accumulative diagram. NR: fluvial deposit; NS: littoral deposit, in normal distribution; NG: glacial deposit; NP: periglacial deposit, in Rosin's diagram.

5 Conclusions

(1)The grain size composition of the deposits around Great Wall Station of China is different. From periglacial deposit to glacial, fluvial and littoral deposit, the mean content of sand increases from 62% to 78%, 90% and 100%; silt decreases from 28% to 18%, 8% and 0; clay decreases from 10% to 4%, 2% and 0;

(2)In order of periglacial, glacial, fluvial and littoral deposits, the grain size parameters shows poor, poor, relative poor and good sorting; mean size falls at extremely fine, fine, median and coarse sand; skewness changes from extremely positive to nearly symmetry; kurtosis is unregular;

(3)The differenciation of the frequency curves is the reflection of process mechanism. The fluvial and littoral deposits follow normal distribution, they are single or broken lines in normal accumulative diagram;

(4)The glacial and periglacial deposits follow Rosin's distribution, they are single or broken lines in Rosin accumulative diagram.

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