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A quantitative analysis on the sources of dune sand in the Hulun Buir Sandy Land: application of stepwise discriminant analysis (SDA) to the granulometric data

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Abstract: Quantitatively determining the sources of dune sand is one of the problems necessarily and urgently to be solved in aeolian landforms and desertification research. Based on the granulometric data of sand materials from the Hulun Buir Sandy Land, the paper employs the stepwise discriminant analysis technique (SDA) for two groups to select the principal factors determining the differences between surface loose sediments. The extent of similarity between two statistical populations can be described quantitatively by three factors such as the number of principal variables, Mahalanobis distance D^2 and confidence level α for F-test. Results reveal that: 1) Aeolian dune sand in the region mainly derives from Hailar Formation (Q_3), while fluvial sand and palaeosol also supply partially source sand for dunes; and 2) in the vicinity of Cuogang Town and west of the broad valley of the lower reaches of Hailar River, fluvial sand can naturally become principal supplier for dune sand.
Key words: Hulun Buir Sandy Land; granulometric analysis; stepwise discriminant analysis; dune sand; Hailar Formation; fluvial sandy sediments

Hulun Buir Sandy Land is located in the highest latitudes (47-50°N) among the famous sandy lands in China, where about 6411 km^2 of sand dunes are scattered on the vast expanse of the Hulun Buir Steppe (Zhong, 1998). Large stretches of dunefields which exist and continuously evolve affect deeply the stability of grassland ecosystems and the sustainability of regional socio-economic development. Therefore, it is practically crucial to make certain the source of dune sand in this region for developing the scientific and feasible prevention and rehabilitation policies and the formulation of the planning and strategies for regional resources exploitation.

Only based on the profound and systematic field investigations and observation, can the source of dune sand necessarily be determined in accordance with the similarity between dune sand and other loose sediments exposed to the air through detailed analyses and comparisons. Granulometric analysis is one of the conventional means to determine the principal sources of dune sand in aeolian landforms and desertification research, mainly by analyzing and comparing the grain-size parameters (i.e. mean, standard deviation, skewness, kurtosis etc.) from graphic or moment techniques. The method is, however, essentially qualitative and lacks thorough quantitative analysis, by which the similarity can not be manifested quantitatively between different loose sediments on the surface. In the paper, the stepwise discriminant analysis technique (SDA) for two groups is designed to select the principal factors determining the differences between various loose sediments, quantitatively calculate the meaningful indicators, deduce related key surface processes, and finally determine the sources of dune sand with certain numerical indicators.

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1 Regional setting

1.1 General physical geographic features

Hulun Buir Sandy Land lies on the Hulun Buir Steppe, northeastern fringe of the Mongolian Plateau. The elevation is generally between 500 and 800 m with relative flat relief. It is embraced by mountains except the southwest, open to the vast plateau. It is characterized by the temperate semi-arid and semi-humid climates: annual mean temperature -3-0°C, annual precipitation 240-400 mm, concentrating in summer (July-August); longer frigid and dry winter, windy spring with frequent gales (with wind velocity ≥ 17.0 m/s normally exceeding 40 days), shorter warm and humid summer and transient autumn. There are many rivers across the region such as Hailar, Yimin, Hui, Krulun, Ulxun rivers, etc. and a number of lakes and ponds (Figure 1).

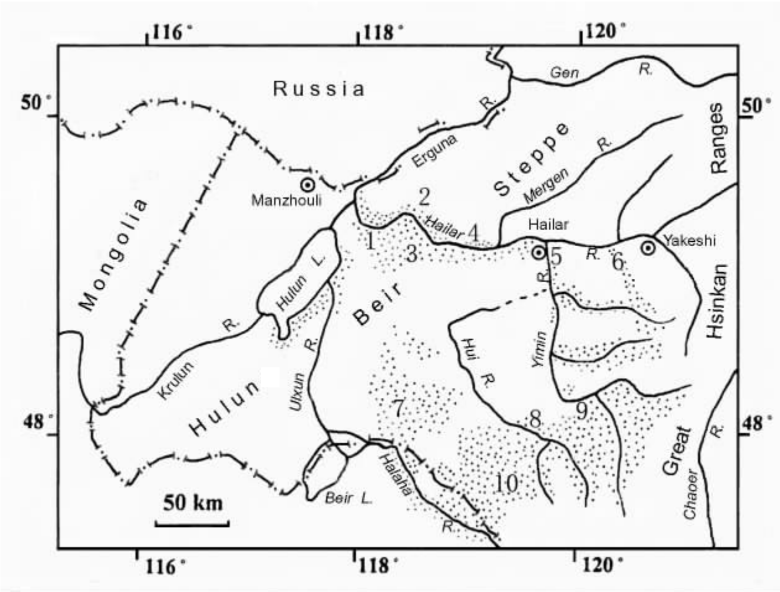

Figure 1 Skeleton map of research region
1) Cuogang Town; 2) West Wuzhur; 3) Herhongde; 4) East Wuzhur; 5) Hailar City; 6) Shunhe; 7) Amugulang Town; 8) Huihe Forest Farm; 9) Honghuaerji Town; 10) Baritu Forest Farm

The region covered by the meadow steppe is mainly composed of *Stipa baicalensis*, *Aneurolepidium chinense*, *Tanasetum sibiricum*, etc. and the typical steppe (dry steppe) of *Stipa grandis*, *S. krylovii*, *Cleistogenes squarrosum*, *Artemisia frigida*, etc. Correspondingly, main soil types include chernozem soil and chestnut soil.

1.2 Features of aeolian landforms

The aeolian dunes in this region are concentrated in the Hailar tectonic basin south of the Hailar River, covering the underlying Hailar Formation which is comparatively identical grey-white fine sand of late Quaternary (Q_3). Controlled by the secondary tectonic depression structures, the distribution of dunes shows certain spatial disparity. The areas with denser and well-developed dunefields are clustered along Hailar River, the zone extending from Amugulang Town (the western end) through the Huhe Lake to Toudaoqiao (the eastern end)–a site by the bank of the upper reaches of Yimin River (Chen, 1981). Moreover, besides the northern dunefield belt–the Hailar Dunefield Belt, central dunefield belt (very small in spatial scale), southern dunefield belt and the dunefield belt on the eastern shores of Hulun Lake, there are still some large-scale dunefields discovered along Shunhe River–a tributary of Hailar River and Sini River–a tributary of Yimin River, and in the western hill and lower mountainous areas of the Great Hinggan Ranges, which are all situated in the eastern fringe of the high plain, by means of detailed field investigations and indoor remote sensing imagery analysis.

Thanks to rich precipitation and flourishing vegetation in warm seasons, dunes in the region are generally stabilized or semi-stabilized, in the forms of honeycomb-shaped dunefields and honeycomb-shaped dunefields overlapping on sand ridges. The heights of the mass of dunes are fallen into the range of 5-15 m (Zhu *et al.*, 1980). In the areas with less human activities, there exists an undulate sandy steppic landscape. What is more, in the southeastern forest of *Pinus Sylvestris var. mongolica* on sandy lands, windblown dunes had been devoured by the forest. While in the areas with frequent and intensive human activities, mobile dunes increasingly expanded and developed so quickly that the grid-shaped dunefields emerge in some places due to the destruction of vegetation, for example, in the vicinity of Amugulang Town, Cuogang Ranch, the mouth of Sini River. In addition, in the central part of southern dune belt, one can easily encounter many separate crescent dunes and parabolic dunes, the spatial arrangement of which indicates the local predominant winds from NW.

2 Samples and methodology

2.1 Collection of samples and analysis

During field investigation, the emphases of research were placed on the large-scale northern and southern dunefield belts in accordance with the distribution and development features of windblown dunes. Four dune profiles were chosen, viz. Dongshan of Hailar, East Wuzhur (the northern bank of Hailar River), Herhongde and Amugulang Town, and the samples collected include surface aeolian sands, underlying palaeosol sands and downwards sands from the Hailar Formation at the middle position of upwind slope of dunes. Meanwhile, a soil profile under the forest of *Pinus Sylvestris var. mongolica* on sandy lands was sampled, 15 km away from southwest of Honghuaerji Town, collecting upper layer, central layer and the lower Hailar Formation respectively. In all, sample profiles sum 5. When collecting, select the typical positions, dig in the light of 5-point patterns like a prune flower, each of which keeps 10 cm in thickness. All samples were amply mixed and desiccated under natural conditions in order to be used for granulometric analysis. Furthermore, additional samples from the Hailar Formation were collected at different sites, namely Xishan of Hailar, Baritu Forest Farm, West Wuzhur, Shunhe and Honghuaerji Town, for the purpose of improving the convincingness.

Since fluvial sands exist extensively throughout the region, four fluvial samples were collected from a point-bar of Hui River adjacent to Huihe Forest Farm, the shore of Yimin River north of Honghuaerji Town, a central bar of Yimin River near the Old Bridge of Hailar and a point-bar of lower reaches of Hailar River northwest of Cuogang Town, respectively. In addition, for purposes of deducing the causes and the relative surface processes experienced in the past, the yellow aeolian dune sands in dunes and in the soil profiles under forest were collected as unknown group.

In the study, 28 samples for SDA were prepared in the field, among which nine are from the Hailar Formation, five from windblown dunes, six from sandy palaeosols, four from fluvial sands and four from unknown group with vague features. The samples were analyzed in the interval of 1/4ϕ using the traditional granulometric analysis techniques.

2.2 Calculation of grain-size parameters

Firstly, find the mode from the granulometric analysis data for each sample. Then, calculate for each sample $\overline{X_\phi}$, σ_ϕ, SK_ϕ and K_ϕ, respectively, according to the formula given by Folk & Ward (1957) as follows:

$$\overline{X_\phi} = \sum fm/100$$

$$\sigma_\phi = \left[\sum f(m - \overline{X_\phi})^2/100 \right]^{1/2}$$

$$SK_\phi = \sum f(m - \overline{X_\phi})^3/100\sigma_\phi^3$$

$$K_{\phi} = \sum f(m - \overline{X_{\phi}})^4 / 100\sigma_{\phi}^4$$

where f is the frequency of each size fraction (percentage in weight), and m the median of each size fraction (ϕ).

2.3 Technical requirements of SDA

SDA is a mature set of techniques in the family of statistical techniques. At present, many commercial softwares including SDA are circulated such as SPSS, SAS/STAT, STATISTICA, MINITAB, S-PLUS, MATLAB and the like. SDA is established and ameliorated based on the general discriminant analysis (DA) founded by Fisher (1936). In 1964, Sahu (1964) introduced it into granulometric analysis and this technique was then commonly accepted and appraised because of its satisfactory results in discriminating different sedimentary environments. Moiola and Spencer (1979) thought it most effective in differentiating aeolian sands from other sediments with grain-size parameters. Nevertheless, the immediate facts must be noticed that it would be ambiguous as incorporating the grain-size data with grain-size parameters, each variable contributes varying variance to the population, and that each variable gives the additional information changes sharply in quantity. All these cast, undoubtedly, adverse effects on the effectiveness and practicability of DA. As a result, there is the necessity to manage to screen variables and delete those factors with less influence on the population. Under this circumstances, SDA emerges and are extensively applied to numerous fields such as socio-economics, medicine and psychology, geosciences (e.g. meteorology, pedology, geology etc.) and ecology.

2.3.1 Selecting variables In order to obtain reasonable explanation of the calculating results, recalculation of granulometric analysis data was implemented in light of such 5 size fractions as coarse sand (X_1), medium sand (X_2), fine sand (X_3), very fine sand (X_4), and silt and clay (X_5). When calculating, the category of very coarse sand was not separately introduced into variable set, but integrated into the coarse sand because of their very low concentrations in each sample and their very low occurrences among all the samples. As the content in silt and clay is far little, thus incorporating the two as a variable is suitable in this study. Consequently, the five variables, together with the four parameters from moment method and the mode, amount to 10 variables in SDA, viz. X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, and X_{10}.

2.3.2 Technical paths

(1) Calculating method. Generally, the more the similarity between two things, the less the factors determining their differences between them, and the smaller the distance between them. Windblown dune sands (S_d), the sands from the Hailar Formation (Q_3), fluvial sands (S_f) and palaeosol sands (S_p) either exposed to the air or buried in dunes are primary loose sedimentary sands widely distributed in the region, experience frequent and intensive wind action, at least in windy seasons, and the differences between them are very significant and conspicuous. So, these sediments can be viewed as different statistical populations.

Under common circumstances, researchers, at first step, establish discriminant functions for multiple groups with much more variables, and then classify the unknown samples. On the contrary, this study seeks a novel routine to determine the variables controlling the differences between groups using the SDA for two groups in the case of which different groups had been rightly determined in the light of certain standards. This routine proves very fruitful (Berg, 1980; Han *et al.*, 1999; 2002).

The main thinking way of the authors in the paper is to calculate the degree of similarity or difference for each couple of groups by SDA based on the Bayes' criterion, and further to analyze the relationships between aeolian sands and various surface sediments. Finally, the nature and intensity of related surface processes can be recognized by performing SDA upon unknown samples.

(2) Selecting suitable model. Before operating SDA, the conformity of covariance matrix must

be examined to decide whether linear or non-linear model can be used to gain ideal results. If covariance matrixes are not equal nonlinear model ought to be employed (Yao and Liu, 1985).

The item $M\ (1-d)$ given by Box is used to examine by χ^2 -test whether the covariance matrixes are equal, according to the likelihood ratio λ'_3 revised by Barlett (Zhang and Fang, 1999). Here

$$M = \ln\lambda'_3 = (n-k)\ln|S| - \sum_{i=1}^{k}(n_i - 1)\ln|S_i|$$

$$d = (2m^2 + 3m - 1)\cdot\left(\sum_{i=1}^{k}\frac{1}{n_i - 1} - \frac{1}{n-k}\right)$$

where S, S_i are the covariance matrixes for total and each group's population, respectively, k the number of groups, n the number of samples, and m the number of variables. The freedom f can be calculated by $m\ (m+1)\ (k-1)/2$.

After operating in computer, $M\ (1-d)$ values for each couple of groups among four groups can be obtained and all are negative (much smaller than 0), while $\chi^2_{0.01}$ values are all more than 60 under proper freedoms, namely, $M\ (1-d) < \chi^2_{0.01}$. This suggests that the zero hypothesis can not be denied, H_0: $V=V_0$, where the covariance matrix between two populations is essentially identical, and χ^2-test results under the confidence level of 0.01 well satisfy the statistical requirements. Therefore, this research can definitely adopt linear discriminant functions.

(3) Determining other necessary parameters. During the calculating process, the threshold F values ought to be decided for determining whether a variable can be selected in discriminant functions or not. Generally, researchers incline to make $F_1 = F_2$. Much higher or much lower threshold F values could produce undesirable results. The thresholds F_1 and F_2 can be determined only in repeated try. After multiple calculation, it turns out to be $F_1 = F_2 = 2.0$.

Err item ε is designated as 10^{-8} to prevent deterioration of matrix.

3 Results and discussion

3.1 Results

After operation the discriminant functions are obtained between groups:

S_d/Q_3: $Y_1 = -1.25 + 0.73X_5$
$Y_2 = -0.51 + 0.40X_5$

S_d/S_p: $Y_1 = -1.27 - 1.31X_5$
$Y_2 = -0.94 + 1.09X_5$

S_d/S_f: $Y_1 = -0.83 + 0.87X_4$
$Y_2 = -1.19 - 1.09X_4$

Q_3/S_f: $Y_1 = -1.45 - 3.70X_5 + 3.83X_6 + 3.69X_7 + 1.93X_8$
$Y_2 = -6.66 - 8.33X_5 - 8.62X_6 - 8.31X_7 - 4.35X_8$

Q_3/S_p: $Y_1 = -0.56 - 0.33X_7$
$Y_2 = -1.03 + 0.50X_7$

S_f/S_p: $Y_1 = -987.98 + 403.30X_3 - 743.64X_4 - 1726.65X_7 - 179.37X_8 - 972.90X_9 - 759.68X_{10}$
$Y_2 = -439.21 - 268.86X_3 + 495.76X_4 + 1151.10X_7 + 119.58X_8 + 648.60X_9 + 506.45X_{10}$

Corresponding results can be generalized as Table 1. D^2 stands for Mahalanobis distance, F_{cal} is the F values calculated, and F_{theo} the F values passing F-test under the confidence level α (Table 1).

3.2 Discussion

3.2.1 Principal sources of windblown dune sands Dunes in Hulun Buir Sandy Land mainly lie on the Hailar Formation (Q_3) and there is, in general, a layer of black or brown palaeosol between them extended horizontally or quasi-horizontally. The modern dune sands are well-sorted, whose σ_ϕ is 0.5-0.6 and 90% of sands fall into the range of 1-4ϕ (0.0625-0.5

Table 1 The results calculated by SDA on different sandy sediments from Hulun Buir Sandy Land

Items	Selected variables	NSV	D^2	F_{cal}	F_{the}	α	DRUG	Post probability
S_d/Q_3	X_5	1	1.07	3.44	3.18	0.10	S_d	0.65
S_d/S_p	X_5	1	3.24	8.83	7.21	0.025	S_d	0.92
S_d/S_f	X_4	1	2.48	5.50	3.59	0.10	S_f	0.88
Q_3/S_f	X_5-X_8	4	22.87	11.52	7.01	0.01	S_f	1.00
Q_3/S_p	X_7	1	0.63	2.27	2.01	0.20	Q_3	0.99
S_f/S_p	X_3, X_4, X_7-X_{10}	6	5485.22	822.78	27.91	0.01	S_p	1.00

Note: NSV is abbreviated from "number of selected variables", and DRUG is from "discriminating results for unknown group"

mm). The contents of fine sands in all samples are over 60%, the majority of modes sits mainly at 2.5ϕ, and mean size is 2.14-2.76ϕ among all samples, suggesting that aeolian sands possess relatively high uniform textures. These results accord with those by former researcher very well (Chen, 1981). Similarly, sands of Q_3 have also uniform texture: 2.37-2.90ϕ for mean size, modes at 2.5ϕ, the grains of 1-4ϕ account for over 90% (fine sands), standard deviation is 0.47-0.89ϕ whose sorting can be said moderate or a bit better. The mechanical composition of size shows certain regional disparity.

With respect to the quantitative relationships between S_d and Q_3, S_p and S_f by SDA, differences between the three relationships are determined by single factor: S_d/Q_3 and S_d/S_p all by the same factor X_5, S_d/S_f by X_4. It can, therefore, be concluded that Q_3 closely accords with S_p in grain-size, but there is certain difference with S_f, which conform to the field survey. Factually, soil is, in the first place, eroded intensively when vegetation is destroyed. Furthermore, if stabilized dunes are denuded off palaeosols in dunes can also supply sand materials for the development of new dunes. Finally, underlying Q_3 sands are exposed to the air. As for S_f, its spatial scale is limited largely and its causes are definitively different from the other three sediments. Among the three couples of relationships, D^2 values are all minute, of which S_d/Q_3 is the least, only 1.07, and the confidence level required by statistical test is very low (α = 0.10). It suggests that the difference is undetermined and unbelievable. The differences between them can be thought very small and their similarity is very large. Accordingly, D^2 value of S_d/S_f is at the second place, D^2 = 2.48, α = 0.10, which shows also the high similarity. That of S_d/S_p is maximum, D^2 = 3.24, α = 0.025, showing the difference is a little obvious. But in general, compared with other studies, the differences between them are not very large, which illustrate that S_d has close genetic linkages with the other three sediments.

S_d is much the same as Q_3 and the deviation between them is merely the item of silt and clay (X_5). The mean content for the former is merely 1.82%, but for the latter as high as 4.5% (Table 2). This accords with one's intuitive perception in field. In general

Table 2 The differences of X_4 and X_5 between dune sand and Q_3 and palaeosol in Hulun Buir Sandy Land

Type of sediment	Sample No.	X_4 (%)	Mean (%)	X_5 (%)	Mean (%)
S_d	h-06	17.57	15.17	1.87	1.82
	h-09	25.84		3.55	
	h-17	11.74		0.18	
	h-36	18.38		2.58	
	h-39	2.33		0.31	
Q_3	h-01	—		4.26	4.50
	h-03	—		0.51	
	h-07	—		5.51	
	h-10	—		1.54	
	h-11	—		1.66	
	h-32	—		10.75	
	h-48	—		6.78	
	h-62	—		5.60	
	h-64	—		3.90	
S_p	h-02	—		10.89	7.14
	h-08	—		1.38	
	h-12	—		4.46	
	h-33	—		6.85	
	h-35	—		7.78	
	h-49	—		11.50	
S_f	h-42	7.85	4.43	—	
	h-43	1.90		—	
	h-61	4.81		—	
	h-63	3.14		—	

cases, Q_3 is protected by vegetation, soil and water bodies from direct wind erosion so that it contains more micro-particles. On the contrary, S_d possesses few micro-particles. Under the condition of gales and dust storms, silt and clay particles are mainly transported in suspension downwind and the remnants are those which move mainly in saltation, which induces significant reduction of silt and clay in dunes. A number of domestic and abroad relevant researches have amply illustrated this conclusion (McTainsh and Pitblado, 1987; McTainsh, 1999; Wiggs, 2001, etc.).

Similarly, the differences of S_d/S_p, on the other hand, are actually caused by reverse processes. When windblown dune sands are stabilized by plants or trapped by water, frequent winnowing by winds terminates. And as plants colonize and soil forms and continuously develops, fine particles are produced by physical disintegration and chemical decomposition of minerals. Meanwhile, airborne dust particles can, from time to time, add into soil due to the block and interception of plants, which further increases the content of micro-particles in soil (Pye and Tsoar, 1990; Cattle *et al.*, 2002; Chen *et al.*, 2002; Singer *et al.*, 2003, etc.). According to the research conducted by Wang and Chen (1996) in the Taklamakan Desert, Xinjiang, China, the content of $\geq 4\phi$ particles can reach 15.15% and 19.76% at the top of dunes and at the foot of windward slopes within windbreaks, respectively. However, the content of silt and clay at equivalent positions outside windbreaks only reaches 0.13% and 2.75%, respectively. It can certainly be concluded that windbreaks can effectively intercept the aerosols in the air currents. As such, it can be deduced that the abundant precipitation and flourishing vegetation in the region can make this effect more intensive and obvious.

The deviation of S_d/S_f is presented by the content of very fine sands (X_4). The value for the former is as 3.42 times as the latter. It is well known that wind and running water are different fluids with quite different viscosity and dynamic characteristics. Under general natural conditions, the competence of wind is limited to transport fine particles in saltation, during which frequent collisions and abrasion by high-speed rotating sands can make the bed sands more fine and well-sorted. Nevertheless, running water can transport pebbles even boulders and its carrying capacity is more powerful, which can carry very fine sands in suspension over long distance. As a result, it makes very fine sands in bed sediments far fewer, while the relative enrichment of it in dune sands is achieved. This proves Liu's view from an aspect that compared with fluvial sands dune sands have sorted very fine sands to the best (Liu, 1980). Meantime, Qian *et al.* (1995) found, in their study on mobile dunes in the southern oasis belt of the Taklamakan Desert, that the predominant size is very fine sands. The fact can be attributed to two factors: its fringe position and apparent alternative interactions between wind and running water. As for this research, very fine sands (X_4) can be used as a key indicator to discriminate S_d from S_f, but the question of whether it could be extrapolated to other regions still needs a lot of researches.

Compared with SDA techniques, traditional cumulative probability curve method has many difficulties in quantitative expression of the similarity between two groups. It can be seen that the curve patterns of five groups are all two-segment patterns and have no coarse tail segments, which suggests the coarse sands are rare (Figure 2). Therefore, it is very difficult to differentiate sedimentary phases only by the patterns of cumulative probability curves. The multiple possible explanations for the same grain-size data gradually interest few researchers with this traditional methods, even suffered injustice and drastic reproaches (Ehrlich, 1983). However, granulometric analysis and their derivative techniques are still playing a very important role in synoptic expression of grain-size characteristics, and they are indispensable and are by no means ignored.

With respect to S_d, the curve patterns of samples are eventually almost identical except sample No. h-36 the curve of which is very unique and the size is a little coarser because of the influence of the weathering and denudation of bedrocks at adjacent highlands. S_d has the similar curve patterns with Q_3. If taking no account of the abnormal h-33 and h-35 which lie

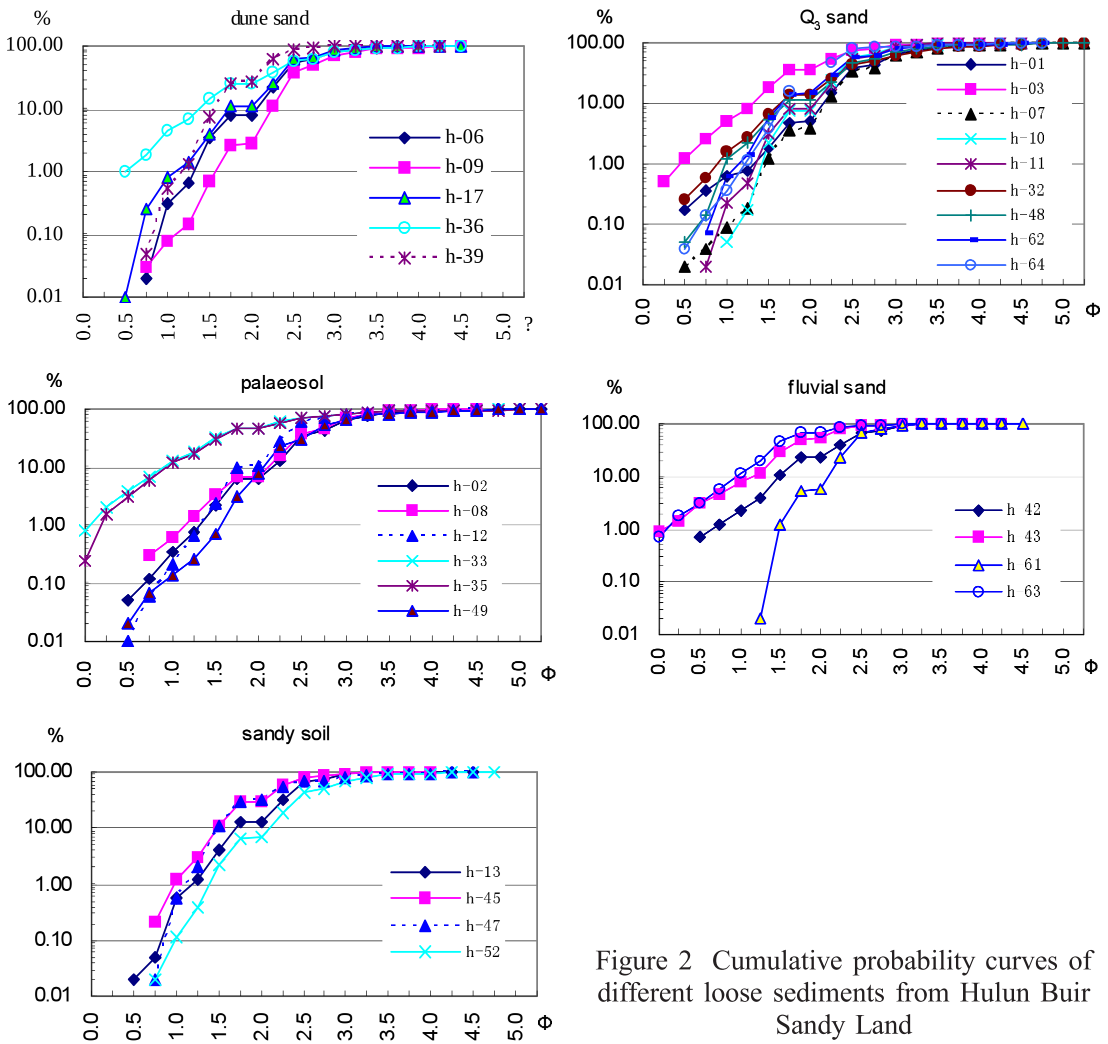

Figure 2 Cumulative probability curves of different loose sediments from Hulun Buir Sandy Land

the same dune profile as h-36, S_d and S_p seem much alike, but the former has a little larger slope in saltation segment. Comparatively, S_d is apparently different from S_f in curve pattern. When the sample h-61, near to Cuogang Town of the lower reaches of Hailar River, is excluded, both have almost the same curve patterns. Errant sample h-61 can be ascribed to two factors: on one hand, the site is located in the lower reaches of Hailar River where the channel gradient is very gentle and its loads are very fine, well-sorted; active windblown sands on beaches, on the other hand, supply a considerable number of sands for dunes. The curve patterns of four unknown samples are much the same as S_d. This accords with the results by SDA. It can be calculated that the intensity of pedogenetic processes under modern climates and vegetation is insufficient to strongly disturb the mechanical composition of soils. Compared to the palaeo-climates when palaeosols formed, modern climatic conditions are generally in their relative dry periods.

Therefore, from the above calculating results together with the thickness of principal sediments and their spatial scale, Q_3 ought to be the most possible and main source of aeolian sands in the region. Q_3 appears on a very large spatial scale and its thickness is comparatively large. However, S_f and S_p also play very important parts in supplying sands for dunes and their parts could not be ignored.

3.2.2 The significance of fluvial sands for aeolian landforms According to the above related analyses, S_d and S_f are much alike, D^2 =2.4766, whose the curve patterns are very similar. Their difference only resides in X_4. The similarity of S_d/S_f implies that fluvial sands can also supply sands for dunes, at least in this research. Because the region is located in plain areas and the flow of the river is slower, fine fluvial sediments are subject to be eroded by winds in dry seasons. Furthermore, the valley becomes broader and broader from upper to lower reaches of a river, alluvial deposits finer and finer, wind action more and more intensive, thus aeolian landforms develop better and better.

From the field surveys and airphoto analysis, the valley of lower reaches of Hailar River in the vicinity of Cuogang Town is very broad and its extension direction accords with local prevailing winds. As a result, large stretches of beaches have been modified into dunefields by winds. Even at some places drifting sands move fast into river or onto grasslands downwind. Less stabilized dunes scatter on the first terrace and at certain places dunefields had become undulatory grassland landscape. Due to comparatively ideal moisture, surface processes on S_f differ sharply from those on S_d. The result that four unknown samples all belong to S_f indicates that modern pedogenetic processes on vegetated dunes and soils under the forest of *Pinus Sylvestris var. mongolica* on sandy lands are eliminating the vestiges of wind actions. That is, the content of very fine sands attenuate gradually so that these processes have certain synchronism with S_f to some extent. Both S_f and S_p have vast distance: not only D^2 value is very large (5485.22) but also the difference is determined by six principal factors and the confidence level for F-test is very strict (α = 0.01, actually it can pass successfully the F-test under α = 0.001). It shows that pedogenetic processes on S_f are very weak simply because of the intensive disturbance on fluvial sediments by the interactions between running water and wind actions.

The problem of the impacts of fluvial landforms on aeolian landforms is manifested very conspicuously in plain areas under semiarid climates, where the actions of wind and running water alternate in seasons and so does the intensity. River can not only supply source sands for dune formation, modify existing dunes, but also change the air current patterns indirectly by engraving valley morphology, especially in meander reaches. Surely, on the contrary, dunes can also exert different effects on fluvial landforms. Therefore, it deserves to pay more attention to the fact that the changes in channel morphology and sedimentary dynamics influence strongly the formation and development of dunefields.

4 Conclusions

(1) Based on the granulometric data of sand materials from the Hulun Buir Sandy Land, the stepwise discriminant analysis technique (SDA) for two groups is used to select the principal factors determining the differences between surface loose sediments. The extent of similarity between two statistical populations is described quantitatively by three factors such as the number of principal variables, Mahalanobis distance D^2 and confidence level α for F-test, by which the experienced surface processes in the past can be deduced. The new routine of SDA can acquire more optimal results than traditional methods.

(2) Aeolian dune sands in the region mainly derive from the Hailar Formation (Q_3), while fluvial sediments and palaeosols also supply partially source sands for dunes.

(3) In the broad valley in the vicinity of Cuogang Town and west of it, the lower reaches of Hailar River, fluvial sands can naturally become principal supplier for dunes.

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