Wind Erosion and Dune Stabilisation in Ningxia, China

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INTRODUCTION

In China, there are 12 deserts or sandy lands. Deserts and desertified land together occupy 1.52 million km^2 or 15.9% of the land area and this area is expanding at an estimated mean rate of 2100 km^2 y^{-1} (Ministry of Forestry, 1992). Desertification is intimately related to aeolian processes and wind erosion. Investigations into these processes are co-ordinated by the Institute of Desert Research of the Chinese Academy of Sciences (IDRAS), which operates nine arid research stations. Desertification and wind erosion processes were investigated at Shapotou Research Station in Ningxia Autonomous Region (Mitchell *et al.* 1996). Shapotou is located on the south-eastern edge of the Tengger Desert (Figure 1).

Desertification is caused by a complex amalgam of environmental and anthropogenic factors. Environmental factors include the natural aridity of central Asia, attributable to distance from maritime sources of moisture and orographic barriers to the penetration of moist summer monsoon winds. Climatic change has also played a role, with the progressive uplift of the Himalayan system believed to be the primary cause of progressive desiccation through the Miocene, Pliocene and Pleistocene. Aeolian processes during the Pleistocene were largely responsible for the separation of arid landscapes into rock (reg, gobi), sand (erg, shamo) and loess landscapes. The climatic changes projected by General Circulation Models predict central Asia will become progressively more arid (Goudie, 1994). Anthropogenic factors causing desertification include overgrazing, undue collection of firewood, over-cultivation, misuse of water resources and political factors. Overgrazing is the dominant anthropogenic factor in north central China (Zhu *et al.,* 1988; Zhu, 1989).

Aeolian Deposition

In north central China, the sequence of gobi, shamo and loess demonstrate that over geological time aeolian processes have been very active. The vast accumulation of loess in the Middle Yellow River valley, in places over 300 m thick, suggest that north-westerly winds have been dominant. Loess at Jiuzhoutai, Lanzhou, is 318 metres thick and is interspersed with at least 34 palaeosols, indicating that accumulation has been discontinuous (Yan, 1991) (Plate 1). The modal loess particle size distribution suggests that aeolian deposition has been the dominant geomorphological process. Dating of the palaeosols provides deposition rates, which can be equated with particular climatic events (Liu *et al.* 1986).

Dune Stabilisation

Shapotou Experimental Station was established in 1956, to find ways of stabilising mobile sand dunes of the Tengger Desert. In 1956, the Batou to Lanzhou railway was constructed through 40 km of the southern Tengger Desert (Plate 2). Therefore methods were required to reduce sand encroachment on the rail track. Besides planting trees as wind breaks, a procedure for establishing an artificial ecosystem on mobile dunes was derived (Chen, 1983; Shapotou Scientific Experimental Station, 1991). The process converts areas with shifting sands with less than 5% vegetative cover to areas of fixed dunes with 30-50% cover. Initially, a sand barrier is established, encouraging aeolian deposition. Behind the sand barrier, straw checkerboards are constructed which increase aerodynamic roughness, thereby decreasing wind velocity and stabilising the surface (Plate 3).

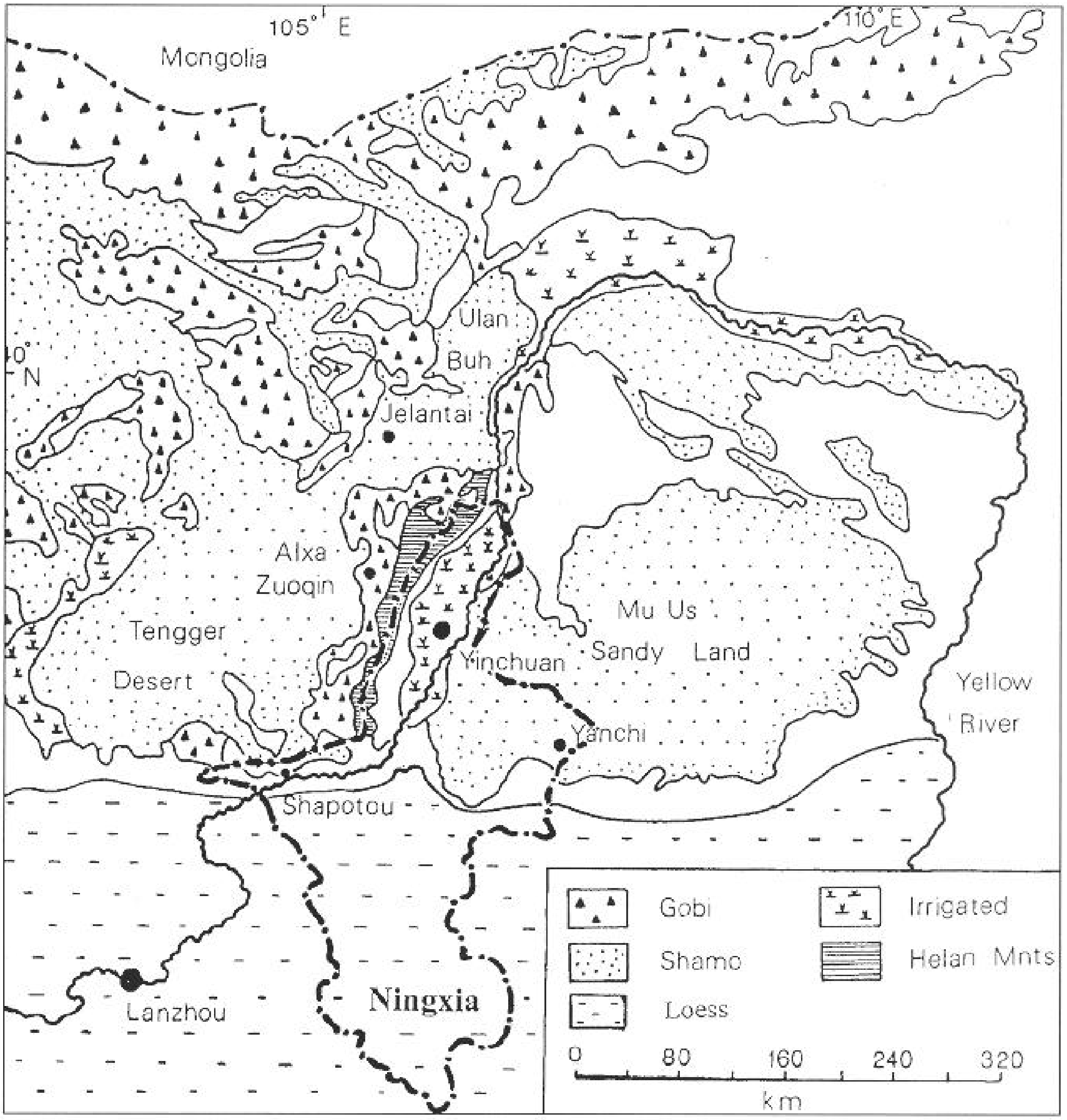

Figure 1. Location of the Tengger Desert and Shapotou.

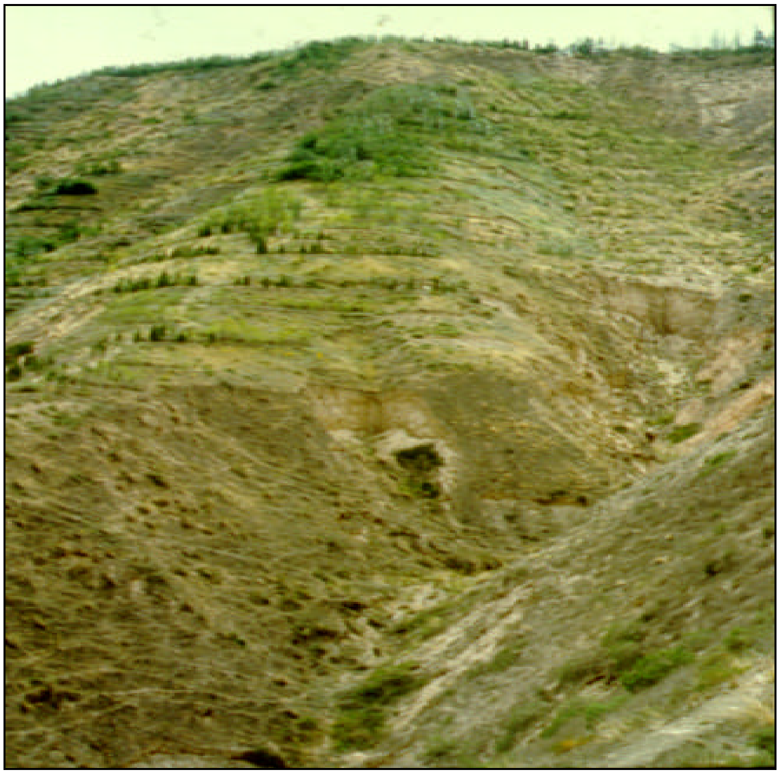

Plate 1. Valley slope at Jiuzhoutai, Lanzhou where the loess is 318 metres thick and interspersed with at least 34 palaeosols, which can be identified by the lines of vegetation.

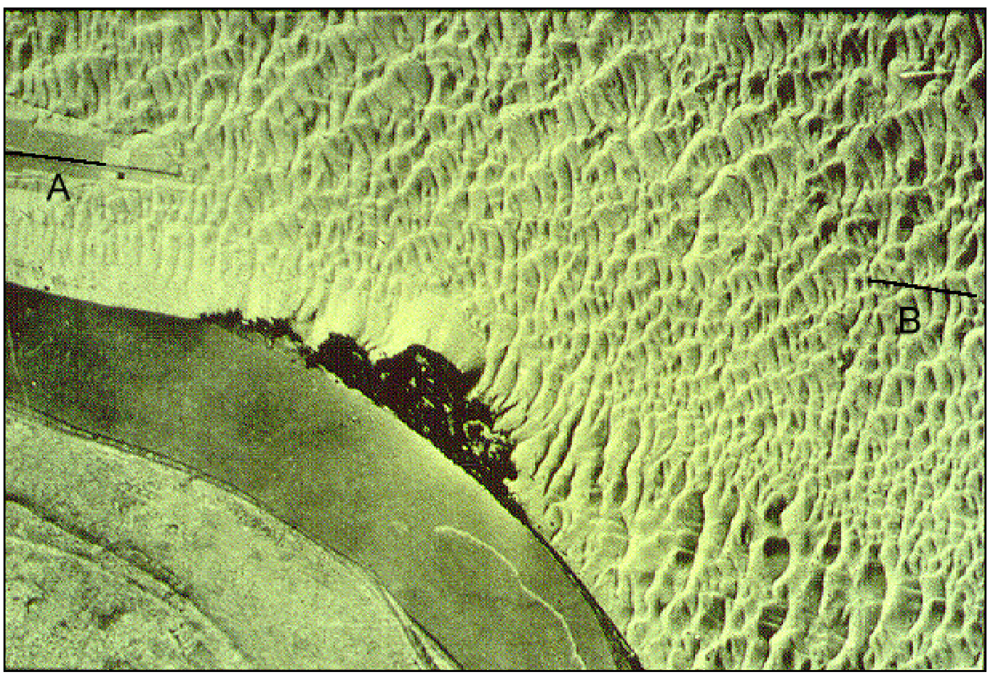

Plate 2 . Aerial view of Shapotou in 1956, showing the mobile dunes of the Tengger Desert reaching the Yellow River which is 300 m wide at this location. The Batou-Lanzhou railway line (A-B) has been engulfed in sand (Institute of Desert Research, Academia Sinica, 1984).

Plate 3. Shapotou in 1990, with the railway line in the background marked by a shelterbelt of pines and poplars and a sand stabilisation experiment in the foreground.

Compared with shifting sand, one meter squared straw checkerboards at Shapotou increased surface roughness length from 0.0025 to 0.89 cm (Liu, 1987; Shapotou Desert Research Station, 1986). Measurements taken during a north-west wind showed that this roughness increase resulted in a hundredfold decrease in sand transport. The checkerboards remain intact for four to five years, allowing time for planted xerophytic plants to become well established. This stabilisation enables the formation of a surface microphytic crust, which protects the surface and increases plant nutrients. Dust trap measurements show that aeolian processes are still active, with the deposition of silt, clay and fine sands rather than coarse sands. As a consequence of dune stabilisation, a finer, largely dust-derived surface of 'grey sand' collects, overlying the dune sand. The aim of this research was to assess contemporary dust deposition on the south-eastern edge of the Tengger Desert by measuring dustfall and accumulation.

MATERIALS AND METHODS

At Shapotou and other IDRAS field stations, stabilisation and reclamation techniques are monitored under a detailed research programme (Zhu and Liu 1988, Liu *et al.* 1994). Well documented sites established since 1956 at Shapotou enable comparative investigations. Using several chronosequences, detailed field research was undertaken by the authors in 1990, 1993 and 1994 (Mitchell and Fullen, 1994; Fullen and Mitchell, 1994; Fearnehough *et al.*, in press). At Shapotou two approaches were used to estimate dust accumulation. Short-term measurements were made using dust traps, while longer term (~ 40 years) deposition was estimated using aeolian deposits on a dune chronosequence. Particle size distributions were analysed using sieving and a CILAS 920 laser granulometer. Samples were treated with hydrogen peroxide and then dispersed using ultrasound and sodium hexametaphosphate.

Dust Trap Measurements
Dust trap design and trapping efficiency have been widely reviewed (Goosens and Offer, 1994). Traps used at Shapotou were similar to the Löbner bucket type (Steen 1979). To assess the influence of topography, five dust traps were located on selected dune facets (Figure 2). Monthly dust accumulation was measured in each trap over a year, but due to rain splash during August, only 11 months (September 1993 to July 1994) were used (Table 1).

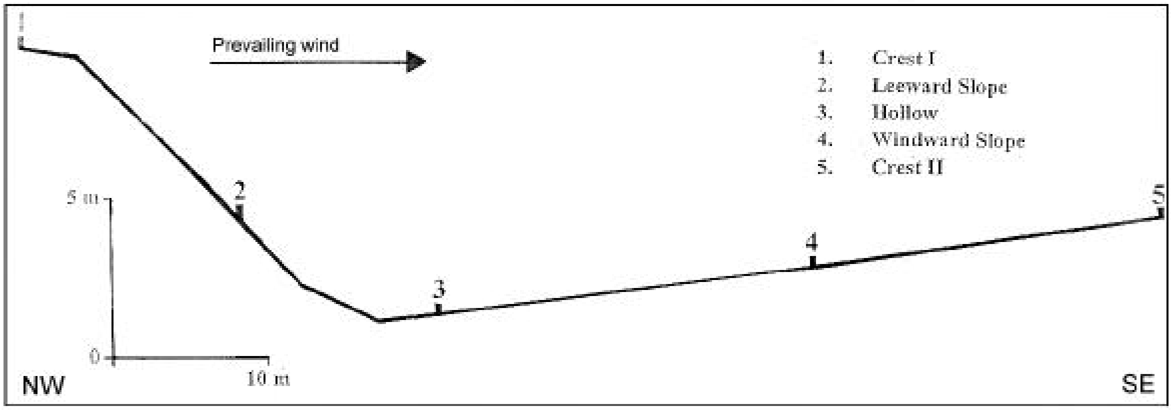

Figure 2. Location of dust traps at Shapotou (Fearnehough *et al.* in press).

'Grey Sand' Deposits
The layer of 'grey sand' is easily distinguished in the field. Therefore 'grey sand' thickness can be used to estimate deposition rates. Extensive tracts of dunes were stabilised in 1956, 1964 and 1981, providing a useful chronosequence. Furthermore, each stabilised area at Shapotou was accurately mapped, providing a unique opportunity to examine the influence of physical and ecological developments of the stabilised surfaces through time. Besides a chronological sequence, the sample areas have a spatial pattern in respect to the distance from the mobile desert dunes. The areas reclaimed in 1956 are close to the railway, while those reclaimed in 1981 are closer to the desert boundary.

Shrub Cover
Dunes stabilised by straw checkerboards in 1981 and planted with shrubs were used to compare the thickness of 'grey sand' with shrub cover. Each shrub is planted in the centre of the 1 m^2 straw checkerboard. Sixty measurements of 'grey sand' thickness were made on unvegetated dunes and 60 measurements under planted *Artemesia ordosica* and *Hedysarum scoparium* shrubs.

Month	Crest I (Trap 1)	Leeward (Trap 2)	Hollow (Trap 3)	Windward (Trap 4)	Crest II (Trap 5)	Mean Monthly
1993 Sept.	10	24	24	8	6	14.4
Oct.	4	7	6	3	4	4.8
Nov.	6	16	12	5	5	8.8
Dec.	9	22	14	7	5	11.4
1994 Jan.	7	14	10	4	2	7.4
Feb.	38	49	40	20	15	32.4
Mar.	41	73	63	24	18	43.8
Apr.	38	45	45	30	24	36.4
May.	39	135	125	39	30	73.6
June	34	72	67	34	27	46.8
July	37	49	49	27	28	38.0
Total	263	506	455	201	124	Mean 309.8
Fraction of Dune Surface	0.075	0.150	0.100	0.600	0.075	
Fraction x Deposition	19.8	75.9	45.5	120.6	9.3	Total 271.1
Particle Size 1/94-7/94						
Mean (µm)	49.8	54.9	70.2	42.9	46.5	
%Clay (<2µm)	3.5	3.1	2.8	3.7	3.9	
% Silt (2-56µm)	52.0	48.6	40.2	60.3	55.3	
% Fine Sand (56-400µm)	44.5	48.3	57.0	36.0	40.8	

Table 1 Monthly deposition (g m^{-2}) at Shapotou (September 1993 - July 1994) (Fearnehough *et al.* in press)

RESULTS

Wind speeds at Shapotou are greatest during late spring (April-May), averaging 3.5 m s^{-1} and are predominantly north-westerly (Li 1988). Dust accumulating over the study period clearly showed that May had the highest rates, with mean monthly deposition of 73.6 g m^{-2} (Table 1). Greatest deflation is associated with the strongest winds, which in turn influences the particle size distribution of dust deposits. Percentage fines (<56 µm) decreased with increased monthly deposition (Figure 3). Dune topography influenced accumulation rates, with the greatest deposition in traps located on the leeward slope and dune hollow. Exposed windward slope and dune crests were subjected to greater deflation, while eddying in the leeward slope and hollow aided dust accumulation. Over the 11 months average dust accumulation from the five traps was 309.8 g m^{-2}. The topography of the dunes resulted in a wide range of deposition rates, from 124 to 506 g m^{-2}. Allowing for the areal extent of each facet in the dune field, the average areal deposition rate decreased to 271.1 g m^{-2} (Table 1). Therefore, in order to measure areal dust deposition, it is important to locate dust traps in a variety of topographical positions. Particle size analysis of deposits collected between January and July 1994 showed that deposition in the dune hollow and leeward slopes was coarser than other facets (Table 1). This may be attributed to sand-sized particles being eroded from the sandy dune crests.

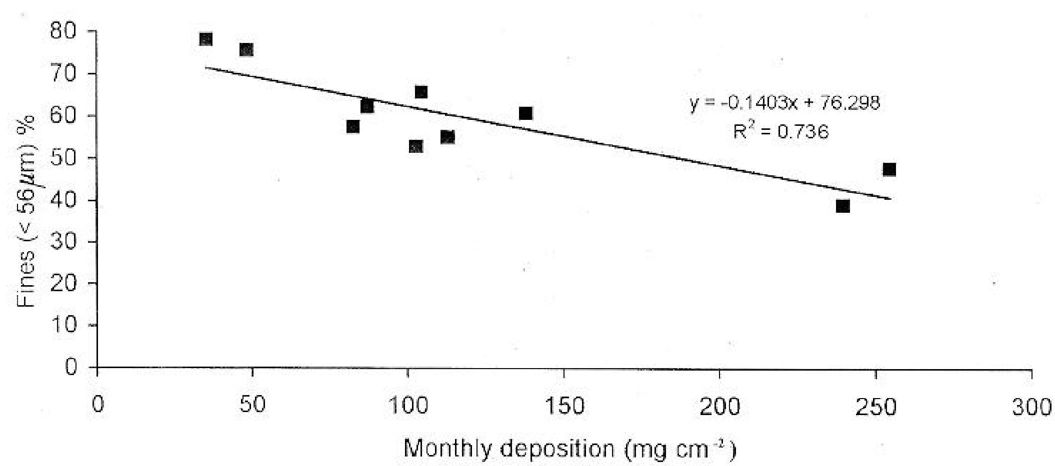

Figure 3 Plot of fine fraction (<56 µm) of deposited dust against monthly deposition at Shapotou (Fearnehough *et al.*, in press).

The mean thickness of 'grey sand' for periods in the chronosequence, indicate accumulation rates between 1.30 and 1.87 mm y^{-1} (Table 2). The mode of particle transportation is related to particle size distribution, as classified by Stahr and Herrmann (1995) (Table 3). Mean particle size distribution decreased with distance from the desert margin, where more wind blown sand occurs. Current deposition on 1956 stabilised dunes clearly lies within the short-term suspension category. As a consequence of the age and development of the cryptogamic crusts on the reclaimed areas, the organic content progressively increased with age (Table 2).

Year of stabilisation	1993 Mobile sand	1981	1964	1956
Years	0	12	29	37
No of samples	30	143	143	149
Mean thickness of grey sand	0	15.6	54.3	59.3
Increase mm y^{-1}	0	1.30	1.87	1.60
Particle size Distribution				
No of samples	9	46	45	46
Mean PSD (µm)	189.97	164.07	125.13	121.52
% Clay (<2µm)	0.41	0.91	1.52	1.75
% Fines (<56µm)	2.31	11.88	25.44	28.34
Loss on Ignition 0-50 mm				
No of samples	40	48	44	47
% Mean LOI	0.26	0.58	0.92	1.17

Note: Loss-on-ignition 375ºC for 16 hours.

Table 2 'Grey sand' accumulation on a chronosequence of surfaces at Shapotou (Fearnehough *et al.* in press)

Transportation Process	Particle Size Distribution (µm)
Creep	> 500
Saltation	70-500
Modified Saltation	70-100
Short-term Suspension	20 -70
Long-term Suspension	< 20

Table 3 Particle size distribution of different transportation processes (Stahr and Herrmann, 1995)

Besides topography, vegetation, especially shrubs, strongly influenced dust accumulation. Using sand dunes stabilised in 1981 and planted with *Artemisia ordosica*, *Hedysarum scoparium* and *Caragana korshinskii* (Plate 4), a positive relationship was found between thickness of 'grey sand' and percentage shrub cover (Figure 4). The mean rate of increase in deposition was 4 mm of 'grey sand' for every 10% increase in shrub cover. Besides shrub cover, shrub structure and form influenced deposition. The shrubs were all planted at the same time, therefore variations in height and structure were mainly governed by species differences. Taking 30 shrubs from each species, taller more open structured *Hedysarum scoparium* accumulated a mean of 37.0 mm of 'grey sand', significantly greater than 29.3 mm under *Artemesia ordosica.*

Plate 4. A sand dune stabilised in 1981 with straw checkerboards and planted *Artemisia ordosica*, *Hedysarum scoparium* and *Caragana korshinskii*

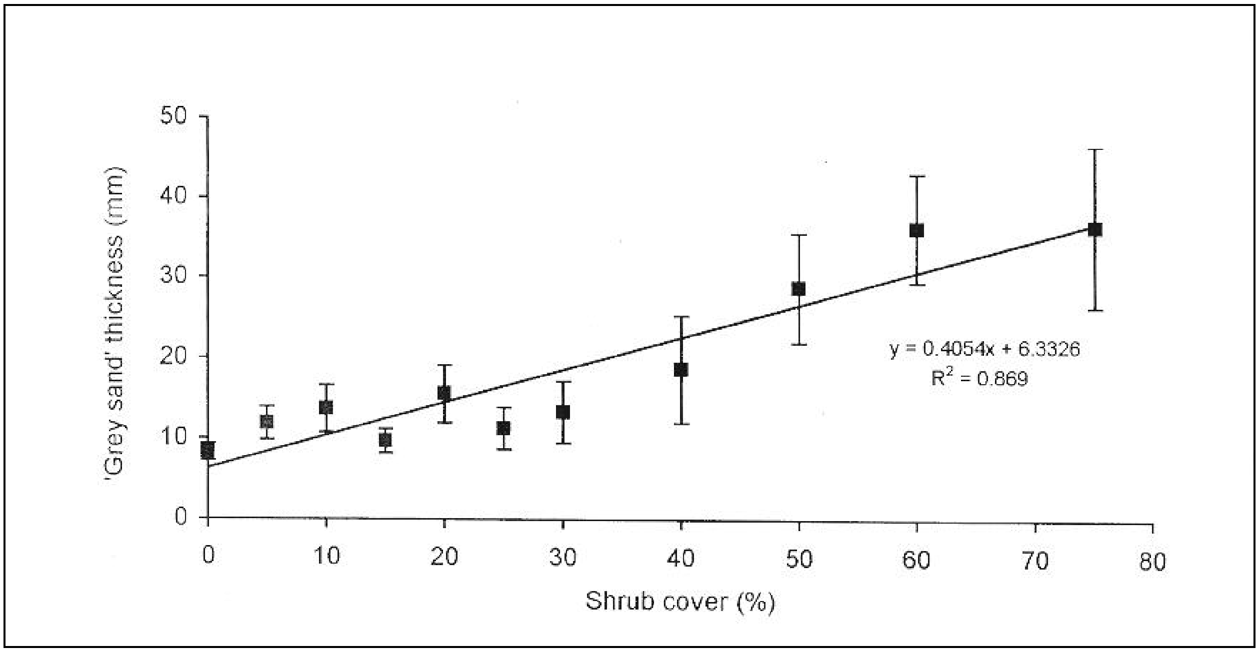

Figure 4. Plot of 'grey sand' thickness against shrub cover on the stabilised dunes at Shapotou (Fearnehough *et al.*, in press).

CONCLUSIONS

The largest loess accumulations have been associated with extreme aeolian processes during the Pleistocene. The vast loess deposits in north-central China indicate that these process were particularly active. Present short-term measurements on the south-eastern edge of the Tengger Desert indicate that similar process are operating today, but not at the same magnitude as during the Pleistocene. Although the field sites are close to the mobile sand dune environment of the Tengger Desert, deposition is associated with dust fall, both in the dust traps and on the fixed dune surfaces. The establishment of an artificial ecosystem at Shapotou and along the Batou-Lanzhou railway, has formed an environment dominated by fine particles (< fine sand). The sites in the chronosequence show that accumulation of these fines are advantageous to grasses and annuals, unlike the former sand dune which encroached the railway prior to 1956. Although the magnitude has been greatly reduced, the aeolian processes and accumulation features can be compared with those of the Pleistocene. The characteristics of airborne dust is relatively homogenous, but at a local scale topographical (dune topography) and ecological (shrub height and structure) controls strongly influence the spatial deposition of dust in the stabilised dune system.

ACKNOWLEDGEMENTS

This research was mainly funded by the Han Suyin Trust, the British Council and The University of Wolverhampton. The authors are grateful to Professors Zhu Zhenda, Song Bingkui, Cho Boaming and Shi Qinhui, and Wang Shu Xiang and Chen Hao of the Institute of Desert Research, Academia Sinica. Lanzhou. The use of the CILAS 920 was by kind permission of Professor A.S. Goudie and analytical support by Mr. C. Jackson, both of The University of Oxford. Mr. N. Musgrove, Mr. M. Hallett and Mr. D.A. Luckhurst are thanked for help with tables and figures.

REFERENCES

Chen Shixiong 1983. The ecological effects of the artificial vegetation on shifting sand of the railway both sides in Shapotou area. *Journal of Desert Research,* **3**(4), 35-41 (In Chinese with English Abstract).

Fearnehough W., Fullen M.A., Mitchell D.J., Trueman I.C. and Zhang, J. Aeolian deposition and its effect on soil and vegetation changes on stabilised desert dunes in northern China. *Journal of Geomorphology* (in press).

Fullen, M.A. and Mitchell, D.J. 1994. Desertification and reclamation in North Central China. *Ambio* 23 (2), 131 - 135.

Goosens, D. and Offer, Z.Y. 1994 An evaluation of the efficiency of some aeolian dust collectors. *Soil Technology* 7: 25-37.

Goudie, A.S. 1994. Deserts in a Warmer World. In Millington, A.C. and Pye K. (Eds). *Environmental Change in Drylands.* J. Wiley, Chichester. p. 1-24.

Institute of Desert Research, Academia Sinica. 1984. A Landscape Map of Desert Control in Shapotou Area of South-east Tengger Desert. 7227 Press.

Li, J. 1988. Wind regime and shifting sand movement in Shapotou area. *Journal of Desert Research* 8(3),41-52 (In Chinese with English abstract).

Liu, T., Zhang, S. and Han J. 1986. Stratigraphy and palaeoenvironmental changes in the loess of central China. In Sibrava, V., Bowen, D.G. and Richrim, G.M. (Eds.) *Quaternary Glaciation in the Northern Hemisphere* Vol 5, Quaternary Science Review. Pergamon Press p. 489-495.

Liu Yingxin, 1987. The establishment and effect of protecting system along the Batou-Lanzhou Railway in the Shapotou Study Area. *Journal of Desert Research,* **7**(4), 1-11. (In Chinese with English Abstract).

Liu Xinmin, Yang Taiyun and Zhao Xingbiang. 1994. Desertification Control Technology in Semi-desert Zones of China: A case study of the Shapotou Experimental Zone, Ningxia. *Chinese Journal of Arid Research* 7(1) , 43-50.

Ministry of Forestry. 1992. Forest Development and Environment Protection in China.

Mitchell, D.J. and Fullen, M.A. 1994. Soil forming processes on reclaimed desertified land in North-Central China. In Millington, A.C. and Pye K. (Eds). *Environmental Change in Drylands.* J. Wiley, Chichester. p. 393 - 412.

Mitchell D.J., Fearnehough, W., Fullen, M.A. and Trueman, I.C. 1996. Ningxia Desertification, reclamation and development. *China Review* 5 Autumn/Winter 1996, p. 27-31.

Shapotou Desert Research Station. 1986. The principles and measures taken to stabilise shifting sands along the railway line in the south eastern edge of the Tengger Desert. *Journal of Desert Research*, **6**(3), 1-19 (In Chinese, English Abstract).

Shapotou Scientific Experimental Station. 1991. Principles and measures of sand fixation in Shapotou area of the Batou-Lanzhou railway. Lanzhou Institute of Desert Research, Academia Sinica, Human and Biosphere State Commission, People's Republic of China (Editor). Ningxia Peoples' Publishing House. (In Chinese).

Stahr, K. and Herrmann, L. 1995. Origin, deposition and composition of dust and consequences for soil/site properties. in M.V. Oppen, B. Bürkert and B.A. Allison (Eds) *The Control of Wind Erosion in Niger: A Case Study.*

Steen, B. 1979. Techniques for measuring dry deposition. In C. Morales (Ed) *Saharan Dust Mobilisation, Transport and Deposition.* Wiley, New York p. 287-289.

Yan M. L. 1991. *Deserts and their remedial measures in Northwest China* Excursion Guidebook IV. International Union for Quaternary Research XIII International Congress, Beijing , China

Zhu Zhenda. 1989. Advances in Desertification Research in China. *Journal of Desert Research*, **9**(1), 1-13. (In Chinese with English Abstract).

Zhu Zhenda and Liu Shu. 1988. Desertification processes and their control in northern China. *Chinese Journal of Arid Land Research* **1**(1), 27-36.

Zhu, Z., Liu, S. & Di, X. 1988. *Desertification and rehabilitation in China*. The International Centre for Education and Research on Desertification Control, Lanzhou.