CHINESE GEOGRAPHICAL SCIENCE
Volume 8, Number 1, pp. 85–90, 1998
Science Press, Beijing, China

THE ANISOTROPY OF LOESS MAGNETIC SUSCEPTIBILITY IN THE NORTHEASTERN FRINGE OF QINGHAI-XIZANG PLATEAU AS AN INDICATOR OF PALAEOWIND DIRECTION

Wang Jianli(王建力)
Geography Department, Southwest China Normal University, Chongqing 400715, P. R. China
(Received 27 November 1996)

ABSTRACT: Estimates of the palaeo-subaerial wind direction were studied systematically for the first time by using the anisotropy of loess magnetic susceptibility (AMS) measurements in the northwestern China. One hundred and forty undisturbed oriented aeolian loess samples were collected from Lanzhou, Linxia and Wudu areas for AMS measurements, which indicated the subaerial wind directions were not the same while the loess deposited. From the Early Pleistocene to Middle Pleistocene till Late Pleistocene, the wind direction experienced an anticlockwise rotation in the studied area. We suggested this change was related to the uplift of the Qinghai-Xizang Plateau and the adjustment of current and landform effects.

KEY WORDS: anisotropy of magnetic susceptibility, palaeo-wind direction, uplift of the Qinghai-Xizang Plateau

I. INTRODUCTION

The anisotropy of magnetic susceptibility (AMS) was first proposed by Graham (1954). As a method of geology analysis, AMS was used rapidly and extensively in the study of all kinds of deposition processes (William *et al.*, 1987). One of them is using AMS as an indicator of sedimentary magnetic fabric to determine and evaluate the sedimentation mechanical direction. A lot of achievements have been made in the determination of palaeo-current direction in deep water of western Indian Ocean (Ellwood, 1980), and Liu Xiuming *et al.* (1989) have studied the sedimentary fabrication of primary and secondary loess using the AMS as an indicator. According to the results, Liu Xiuming *et al.* have successfully distinguished the secondary loess from the primary loess and suggested that the pliocene red earth originated from aeolian dusts. Zhang Yutian *et al.* (1993) also discussed the origin of Xining loess in terms of AMS. In this research, the author will discuss the sub-aerial wind direction affecting the loess deposition process while the AMS is employed as an indicator.

The Qinghai-Xizang (Tibet) Plateau is the highest and youngest plateau in the world. Its uplift and formation exerted a tremendous effect upon the natural environment of China. The evolution of East Asia monsoon and modification of current system have a close relationship with the uplift of the Qinghai-Xizang Plateau. The loess deposition is the result of uplift of the Qinghai-Xizang Plateau, so the information of palaeo-wind direction contained in the loess stratigraphy will be a significant help in comprehending the formation and evolution processes of uplift of the Qinghai-Xizang Plateau.

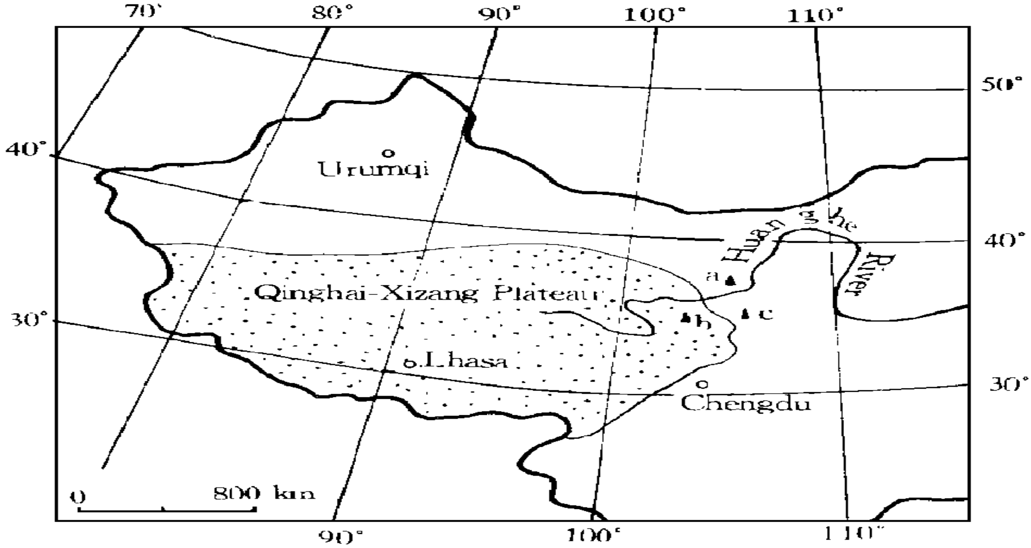
II. PREVIOUS WORK

It has long been known the AMS is one of the essential properties of the sediments or rocks. The AMS data of any rock or sedimentary bulk specimen are conventionally expressed as a triaxial ellipsoid whose major, intermediate and minor axes represent the corresponding maximum (K_a), intermediate (K_b), and minimum (K_c) susceptibility magnitudes and azimuths (Ellwood, 1978). It has been established that the AMS principal axes in rocks are generally controlled by the following: (1) K_c axes align parallel with the axis of maximum compression in the rock, (2) K_a axes for turbulent grain suspensions generally align parallel with the direction of flow, (3) K_a axes align normal to the direction of major compression, and (4) K_a axes are oriented parallel with the direction of maximum strain (extension) (Ellwood, 1982). Taking the aeolian loess as an example, the magnetic minerals contained in the aeolian loess are dominated by ferromagnetic and ilmenitite minerals. In the humid-warm climate conditions, the silts changed into buried soils containing a lot of haematite minerals with higher magnetic susceptibility value. The previous researches suggested that the magnetic fabrication of parent loess had not been changed by the pedogenesis (Liu *et al.*, 1989). The AMS results we measured now could represent the conditions of silts deposited in the geologic time. In the transportation and deposition processes the silts were not only affected by the wind action but also by the gravity. But in the sedimentary process, the main stress affected by the silts is the aeolian action whose direction is parallel to the K_a axis of AMS. According to the AMS theory mentioned above, we can say, the K_a axes of loess AMS, the maximum susceptibility axis, will represent the mean subaerial palaeo-wind direction while the loess deposited.

III. METHODS

1. Field

Total 140 samples were taken from 3 sections on the northeastern margin of the Qinghai-Xizang Plateau. They are Yandonggou section in Lanzhou, Houcun section in Wudu and Dongshanding section in Linxia (Fig. 1).



a. Lanzhou b. Linxia C. Wudu

Fig. 1 Location of loess sections

Yandonggou section is located on the north side of the Huanghe (Yellow) River, about 10 km away from Lanzhou City, its altitude is 1950 m a. s. l. . The section, which lies on an erosion surface, consists of 1-m gravels overlying a 119-m thick loess stratum. The age of the loess bottom is about 1.7 Ma (Zhu *et al.*, 1994), which is known the oldest loess deposits in this area till now. About 93 bulk samples were taken for analysis from the loess bottom to top with 1-m interval.

Dongshanding section is located in the village of Dongshanding 15 km to the west of Linxia City, its altitude is 2429.5 m a. s. l.. The loess section is about 60 m thick. Palaeo-magnetic stratigraphy analysis results showed that the Brunches/Matuyama (B/M) boundary was located at 30-m depth. Seven bulk samples were taken above the B/M boundary, and 26 samples were taken below the B/M boundary.

Houcun section, which lies on the third terrace of the Bailong River, 1095 m a. s. l., 10 km to the northwest of Wudu City, Gansu Province. The loess section is about 17 m thick and the loess bottom has a palaeomagnetic age prior to 0.73 Ma. Fourteen bulk samples were collected at 1-m intervals except the upper 3 m due to the weathering effects.

2. Laboratory

All of these samples were undisturbed oriented blocks (5×5×5 cm) and were cut down to produce smaller oriented blocks (2×2×2 cm) suitable for measurement. Initial susceptibility was measured from 15 directions by using a HKB-1 susceptibility bridge. Each sample was measured carefully. Using the method of the minimum squares, the general susceptibility tensor can be calculated. It can be presented as follows (He *et al*., 1986):

$$[\overrightarrow{K_H}] = [\overrightarrow{A}][\overrightarrow{K}] \quad (1)$$

where $[\overrightarrow{K_H}]$ is the column vectors consisting of several susceptibilities along their directions respectively, $[\overrightarrow{K}]$ is the column vectors of susceptibility symmetrical tensor, and $[\overrightarrow{A}]$ is the coefficient matrix which can be calculated by the oriented cosine in the given coordinate of magnetic field. Equation (1) can be transformed as follows:

$$K_{ij} = a_{ij}K_j \qquad (i = 1, 2, \ldots, j = 1, 2, \ldots, 6)$$

Using the method of matrix inversion (equivalent to multiple linear regression method), $[\overrightarrow{K}]$ can be represented as an explicit function:

$$[\overrightarrow{K}] = [\overrightarrow{K}^T A][\overrightarrow{A}^T][\overrightarrow{K_H}] \quad (2)$$

The author use equation (2) to calculate the susceptibility tensor, furthermore, the major susceptibility (K_a), intermediate (K_b) and minor (K_c) axes representing the corresponding susceptibility directions and magnitude can be worked out. The mean azimuth of major susceptibility (K_a) will represent the major deposition directions of loess particles, in other words, it will represent the mean sub-aerial wind direction while the silts deposited. The results are shown in Table 1.

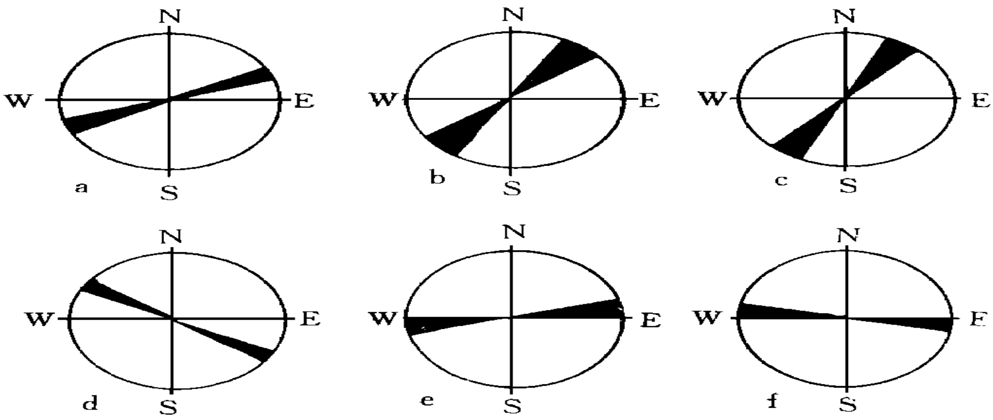
Table 1 Final results of loess AMS on the northeastern margin of Qinghai-Xizang Plateau

Section	Depth (m)	Age (Ma B. P.)	Mean azimuth	Mean palaeo-wind direction
Yandonggou in Lanzhou	10.5–30.0	< 0.73	$\bar{D}$= 205°, 42.5°	NNE–SSW
	31.0–72.0	0.73–1.12	$\bar{D}$= 211°, 52.6°	NE–SW
	73.0–118.5	1.12–1.63	$\bar{D}$= 211°, 71°	NEE–SWW
Dongshanding in Linxia	0–30.0	< 0.73	$\bar{D}$= 268.7°, 76°	E–W
	30.0–60.0	0.73–1.67	$\bar{D}$= 298.7°, 121.4°	NW–SE
Houcun in Wudu	0–17.0	< 0.73	$\bar{D}$= 276.5°, 90.6°	E–W

IV. CONCLUSION AND DISCUSSION

The study results are also shown in Fig. 2. In Yandonggou section, at the bottom of 118.5–73 m, in which the palaeomagnetic age is 1.63–1.12 Ma B. P., the mean sub-aerial wind direction was corresponding to NNE; in the middle section of 72–31 m, in which the palaeomagnetic age is 1.12–0.73 Ma B. P., the palaeo-subaerial wind direction was toward to NE; at the top section of 30 m, which was deposited in the Middle Pleistocene period, the mean sub-aerial wind direction transformed to NNE which is very similar to the current wind direction of Lanzhou City in recent 30 years. Moreover, it is very clear that the sub-aerial wind direction has experienced an anti-clockwise rotation change since 1.6 Ma B. P..

At Linxia City, the mean palaeo-subaerial wind direction was NW–SE prior to 0.73 Ma B. P., and in the Middle Pleistocene period (after 0.73 Ma B. P.) the subaerial wind direction changed approximately to E–W direction. In other words, the palaeowind direction has also experienced an anti-clockwise rotation since the Early Pleistocene to the Middle Pleistocene while the loess deposited in this area.



a. Yandonggou 73– 118.5 m b. Yandonggou 31– 72 m c. Yandonggou 12.5– 30 m
d. Dongshanding 30– 60 m e. Dongshanding 0– 30 m f. Houcun 0– 17 m
Fig. 2 Azimuths of K_a in loess section

The results of Wudu showed that the mean subaerial wind direction was NWW – SEE while the loess silts deposited, which is corresponding to the extension of the Bailong River valley.

As mentioned above, the mean subaerial wind directions both in Lanzhou and Linxia regions experienced an anti-clockwise rotation since the Early Pleistocene (1.6 Ma B.P.) to the Middle Pleistocene, though both of the palaeo-wind directions were not the same. These results showed that the monsoon was not static in the Pleistocene period, rather, it was a dynamic evolving system, which was constantly in the process of adjustment. Until the Late Pleistocene period, the current monsoon circulation system was finally formed. These features reflecting the monsoon adjustment processes can be clearly related to the uplift of the Qinghai-Xizang Plateau and its inducing climate and landforms characters. Fang Xiaomin (1994) suggested that the westerlies, winter monsoon and plateau monsoon had played an important role in the transportation of loess particles from west to east China in the process of Malan loess deposited. This can be regarded as the background conditions of loess deposition, but the subaerial wind direction and landform *in situ* also exerted a tremendous effect upon the loess deposition. Furthermore, as a result of upheaval of the Qinghai-Xizang Plateau, the Siberia High intended gradually, together with the appearance of Lanzhou High, making the lower westerlies circulation experience a ellipsoid-form bending along the eastern fringe of the Qinghai-Xizang Plateau (Ye *et al.*, 1988). As a result, the silts carried by air from its source area deposited in Lanzhou region blown by northeastern subaerial wind corresponding with the Huanghe River valley. And in the southern area of Lanzhou City, hindered by Mahan Mt. and Qinling Mt.

the silts deposited in Linxia Basin blown by east-west subaerial wind.

In the Wudu area, the silts carried by the upper air westerlies over the Qinling Mt. and deposited in the Bailong River valley corresponding with the subaerial wind direction *in situ*.

With the upheaval of the Qinghai-Xizang Plateau, the Lanzhou High intended gradually which exerted an important effect on the current air circulation conditions. It is very obvious that on the northeastern margin of the Qinghai-Xizang Plateau the subaerial wind direction has experienced an anti-clockwise rotation since 1.6 Ma B. P. Details need to be studied carefully in the future.

ACKNOWLEDGEMENT

The author would like to thank Prof. Li Jijun for his advise and Dr. Zhong Wei, Prof. Zhang Yutian, Dr. Wang Jianmin for help in collecting samples in the field.

REFERENCES

Ellwood B. B., 1978. Flow and emplacement direction determined for selected basaltic using magnetic susceptibility anisotropy measurements. *Earth and Planetary Science Letters*. (41): 254– 264.

Ellwood B. B., 1980. Application of the anisotropy of magnetic susceptibility method as an indicator of bottomwater flow direction. *Marine Geology*, (34): 83– 90.

Ellwood B. B., 1982. Estimates of flow direction for Call-alkaline welded tuffsand palaeo-magnetic data reliability from anisotropy of magnetic susceptibility measurements: central Sam Juan mountains, southwest Colorado. *Earth and Planetary Science Letters*, (59): 303– 314.

Fang Xiaomin, 1994. Study on the source and cause of Malan loess on east margin and adjacent of Qinghai-Xizang Plateau. *Science in China (Series B)*, 24(5): 539– 546. (in Chinese)

Graham J. W., 1954. Magnetic susceptibililty anisotropy, an unexploited petrofabric element. *Bull Geol. Soc. Am*. (65): 1257– 1258.

He Shaoying, Sun Shiwei, Yang Piyuan, 1986. *Anisotropy of Rock Magnetic Susceptibility*. Beijing: Geology Press, 38. (in Chinese)

Liu Xiuming, Xu Tong Chun, Liu Dongsheng, 1989. The AMS and origin of Chinese loess and their significance in Quaternary research. *Science in China (Series B)*, (4): 441– 448. (in Chinese)

William D MacDonald, Ellwood B. B., 1987. Anisotropy of magnetic susceptibility: sedimentological, igneous, and structural-tectonic applications. *Reviews of Geophysics*, 25 (5): 905– 909.

Ye Duzheng, Gao Youxi, 1988. *Meteorology of Qinghai-Xizang Plateau*. Beijing: Science Press, 44– 60. (in Chinese)

Zhang Yutian, Chen Fahu, Cao Jixiu, 1993. Discussion on the property of loess magnetic susceptibility anisotropy. *Journal of Lanzhou University (Natural Science)*, 29(2): 153– 160. (in Chinese)

Zhu Junjie, Cao Jixiu, Zhong Wei, 1994. Discovery of the highest terrace of Huanghe River in Lanzhou area and the study on the loess Palaeomagnetic Chronlogy. *Study on the Evolution, Environmental Change and Ecosystem of Qinghai-Xizang Plateau*. Beijing: Science Press, 77– 90. (in Chinese)