Variation of summer monsoon intensity on the Loess Plateau of Central China during the last 130 000 a

——Evidence from Rb and Sr distribution

CHEN Jun[1], QIU Gang[1], LU Huayu[2] and JI Junfeng[1]

1. Department of Earth Sciences, Nanjing University, Nanjing 210093, China; 2. Xi'an Laboratory of Loess and Quaternary Geology, Chinese Academy of Sciences, Xi'an 710061, China

Keywords: paleomonsoon, loess, paleosol, Rb and Sr geochemistry.

THE loess-paleosol sequences from China potentially provide one of the best terrestrial records of past climates. Studies have shown that magnetic susceptibility in the sequences represents a proxy climate index closely related to changes of summer monsoon intensity[1,2]. Some interpretative models have been advanced to account for these magnetic variations, although unanimity of opinion has not been reached[3]. Recent geochemical studies of chemical weathering on the Loess Plateau by the present authors show that some trace element ratios of the loess to paleosol can reflect the regional climate. Here we present results of Rb/Sr ratio and magnetic susceptibility obtained from the Luochuan loess-paleosol section and have some discussion about the relationships between variation of Rb/Sr ratio and fluctuations of climate.

1 Sampling and analysis

The Luochuan loess-paleosol section is located 5 km south of Luochuan City, Shaanxi Province (35°45′N, 109°25′E). The upper part of the section (fig. 1) spans the last 130 000 a. From the surface downward, the sediments consist of the Early to Middle Holocene paleosol (S_0); the Malan loess (L_1), deposited during the last glaciation; and paleosol S_1 of last-interglacial age. A weak paleosol complex (L_1SS_1) in the middle of the loess can be divided into an upper loess unit (L_1LL_1) and a lower one (L_1LL_2). The section was sampled at 20-cm intervals, resulting in 58 samples for laboratory analyses.

Magnetic susceptibility of all the samples was measured with a Bartington MS2 meter in the Xi'an Laboratory of Loess and Quarternary Geology, while Rb and Sr contents for each sample were determined by using X-ray Fluorescence method (XRF) in Nanjing University. The precision of Rb and Sr analyses is $\pm 1(\times 10^{-6})$ as indicated by duplicate measurements.

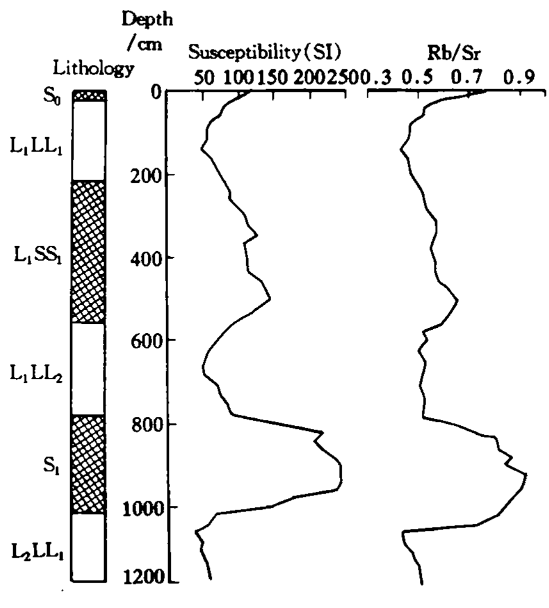

Fig. 1. Comparison of Rb/Sr ratio with the magnetic susceptibility variation in the Luochuan loess-paleosol section.

2 Results

Rb and Sr contents as well as magnetic susceptibility are given in table 1. Rb contents of

Table 1 Results of Rb, Sr and magnetic susceptibility analyses of the loess-paleosol sequence from Luochuan, Central China

Horizon	Sample No.	Rb ($\times 10^{-6}$)		Sr ($\times 10^{-6}$)		Rb/Sr		Magnetic susceptibility	
		range	average	range	average	range	average	range	average
S_0	2	101—111	106	141—165	153	0.61—0.79	0.70	97—125	111
L_1LL_1	10	91—97	94	177—212	200	0.43—0.53	0.47	51— 80	65
L_1SS_1	17	100—105	102	163—195	179	0.51—0.64	0.57	88—143	112
L_1LL_2	11	94—100	98	187—199	192	0.49—0.53	0.51	49— 87	66
S_1	11	110—121	116	129—176	142	0.63—0.91	0.82	141—239	205
L_2LL_1	7	83— 97	91	192—203	196	0.42—0.51	0.47	34— 56	48

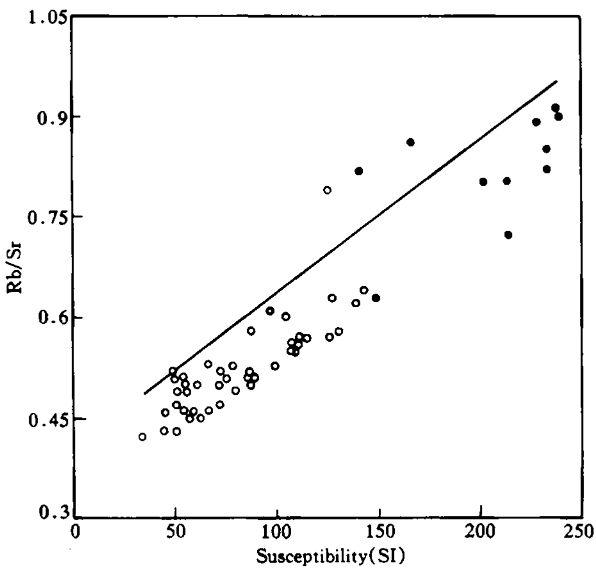

Fig.2. Relationship between Rb/Sr ratio and magnetic susceptibility for the 58 loess and paleosol samples from the Luochuan section of Central China. ●, Paleosol; ○, loess.

paleosols are evidently higher than those of loess, whereas Sr contents are much lower in paleosols than in loess. This makes Rb/Sr ratios in paleosols obviously greater than those in loess. Just the same as magnetic susceptibility, Rb/Sr ratio can be used to discriminate paleosols from loess units in the section.

Figure 1 shows distribution of Rb/Sr ratio and magnetic susceptibility in the seciton. It is evident that the two distribution curves coincide with each other. Regression calculation indicates that there is a very good linear relationship between the two parameters (figure 2):

$$Y = 0.0022X + 0.41 \ (R^2 = 0.930),$$

where Y is Rb/Sr ratio and X is magnetic susceptibility (SI). Because variation of magnetic susceptibility in the loess-paleosol sequence is directly related to variation of summer monsoon intensity, changes of Rb/Sr ratio recorded in these paleosol and loess samples could also be a response to the climate changes in the last 130 000 a.

3 Rb/Sr ratio distribution and summer monsoon variation

Rb and Sr are typical dispersive trace elements. It is known that ion radius of Rb (1.47 Å) is similar to that of K (1.33 Å), and ion radius of Sr (1.13 Å) is similar to that of Ca (0.99 Å). So Rb tends to be dispersed in K-containing minerals, such as muscovite, biotite and K-feldspar; while Sr tends to be dispersed in Ca-containing minerals, such as plagioclase, amphibole, pyroxene and carbonate. Some studies on weathered rocks and sediments have shown that Ca- and Sr-rich minerals decompose more readily than K- and Rb-rich minerals under surface conditions, resulting in the marked fractionation of Rb and Sr[4]. Investigations of weathering profiles in many crustal rocks reveal that Rb/Sr ratio in progressively weathered rock increases compared to Rb/Sr ratio of the fresh rock, and enrichment of Rb over Sr is evident in all the studied profiles[5], implying that Rb/Sr ratio could indicate intensity of weathering of the surficial rocks and sediments.

Variation of Rb/Sr ratio in a weathering profile mainly depends on loss of Sr[5,6]. During leaching and eluviation, Rb can be adsorbed by clay minerals and retained *in situ* because of its larger radius, whereas the smaller Sr is readily removed by surface water or underground water, leading to increment of Rb/Sr ratio in relict. Therefore, variation of Rb/Sr ratio in a weathering profile is essentially related to extent of leaching and precipitation. It should be pointed out that the amount of precipitation represents intensity of the East Asian summer monsoon. During the domination of the summer monsoon, precipitation on the Loess Plateau is heavier, leaching and eluviation are stronger and the loss of Sr is greater, resulting in higher Rb/Sr ratios in the paleosols. This means that Rb/Sr ratio can be used to estimate variation of precipitation and thus summer monsoon intensity on the Loess Plateau.

From fig. 1 it can be found that variation of Rb/Sr ratio in the Luochuan loess-paleosol section is coincident well with the history of summer monsoon activity on the Loess Plateau, as indicated by variation of magnetic susceptibility during the last 130 000 a. Rb/Sr ratio curve exhibits three periods of enhanced summer monsoon, including the Last Interglacial, the interstadial of the Last Glacial and the Post Glacial. During the Last Interglacial (analogous to stage −5 of the $\delta^{18}O$ chronology[7]), the Rb/Sr ratio is higher than during any subsequent time, with a range of 0.63—0.91 and an average value of 0.82 (table 1), implying a stronger summer monsoon and warm-humid climatic condition. It is interesting to note that Rb/Sr ratio in the S1 paleosol displays three peaks which are in correspondence with the three dominant periods of summer monsoon during the Last Interglacial[8].

L_1SS_1 is a weak paleosol complex formed during the interstadial of the Last Glacial (analogous to stage −3 of $\delta^{18}O$ chronology) when summer monsoon was intensified[2]. Rb/Sr ratio in L_1SS_1 ranges from 0.51 to 0.64 and averages 0.57, much higher than Rb/Sr ratio in L_1LL_1 which represents the Last Glacial maximum. This means that Rb/Sr ratio can sensitively reflect oscillation of paleoclimate. S_0 paleosol was formed in the Post Glacial (stage −1 of $\delta^{18}O$ chronology), and Rb/Sr ratio in it averages 0.70 which is situated between the values from the S_1 and the L_1SS_1. This implies that the intensity of summer monsoon during the Post Glacial could be weaker than that during the Last Interglacial, but stronger than that in the interstadial of the Last Glacial.

Based on the above evidence, Rb/Sr ratio in the loess-paleosol sequence is linked to and controlled by the intensity of the summer monsoon. Therefore, Rb/Sr ratio can be used to reconstruct the variations of summer monsoon intensity in Central China during the Late Quaternary. Moreover, the coincidence of Rb/Sr distribution with magnetic susceptibility distribution in the sequence might reflect some genetic relationships of the two parameters. Further studies should take into account the relations while investigating the paleoclimate changes over the Loess Plateau.

(*Received May* 2, 1996)

References

1 An, Z. S., Liu, T. S., Liu, Y. C. *et al.*, The long-term paleomonsoon variation recorded by the loess-paleosol sequence in Central China, *Quat. Intern.*, 1990, 8(7): 91.

2 An, Z. S., Kukla, G. J., Porter, S. C. *et al.*, Magnetic susceptibility evidence of monsoon variation on the Loess Plateau of Central China during the last 130 000 years, *Quat. Res.*, 1991, 36: 29.

3 Maher, B. A., Thompson, R., Paleoclimatic significance of the mineral magnetic record of the Chinese loess and paleosols, *Quat. Res.*, 1992, 37: 155.

4 Goldich, S. S., Gast, P. W., Effects of weathering on the Rb-Sr K-Ar ages of biotite from the Morton Gneiss, *Minnesota*.

Earth Planet. Sci. Lett., 1966, 1: 372.

5 Dasch, E. J., Strontium isotopes in weathering profiles, deep-sea sediments, and sedimentary rocks, *Geochim. Cosmochim. Acta*, 1969, 33: 1521.

6 Bottino, M. L., Fullager, P. D., Effects of weathering on whole-rock Rb-Sr ages of granitic rock, *Amer. J. Sci.*, 1968, 266: 661.

7 Martinson, D. G., Prisias, N. G., Hays, J. D. *et al.*, Age dating and the orbital theory of the ice ages: Development of a high-resolution 0 to 300 000 a chronostratigraphy, *Quat. Res.*, 1987, 27: 1—29.

8 Porter, S. C., An, Z. S., Correlation between climate events in the North Atlantic and China during the Last Glaciation, *Nature*, 1995, 375: 305.

Acknowledgement The authors are very grateful to Prof. An, Z. S., Xi'an Laboratory of Loess and Quaternary Geology, for his encouragement, to Profs. Wu, X. H. and Ding, Z. L. for their helpful suggestions.