

Study of elemental distribution in soil on the loess plateau of China

Tian Junliang, Li Yaqi and Liu Puling

Northwestern Institute of Soil and Water Conservation,
Chinese Academy of Sciences, Shaanxi 712100, China

Abstract — Instrument neutron activation analysis (INAA) has been employed in this study to determine 32 elements in soil on the loess plateau. The preliminary results suggest that geochemical characteristics of elements in the soil mainly retained those in the parent materials (loess). It has been found that fractional deposition among grain sizes in the process of loess transportation as well as the bioclimate in which the soil developed are main factors affecting the regional variations of elemental distribution in soil on the plateau. Contour maps of element concentrations plotted from the trend analyses exhibit the major patterns of the distributions and variations on the plateau. Furthermore, the study also provides evidence for the aeolian theory of the loess transportation in China.

Keywords: elements; soil; loess plateau; variation patterns.

INTRODUCTION

Loess plateau located in the middle reaches of the Yellow River was the cradle of Chinese ancient culture and the birthplace of Chinese agriculture. From northwest to southeast, soil belts in the plateau mainly distributed are Sierozem, Heilu soil (dark loessial soil), and Lou soil (Stratified old manured loessial soil), which are individually related to three types of bioclimatic environments changed in the same direction, i.e. desert/arid grassland, forest-grassland, and forest land. Because of the widely distributed area of loess and the rich environment information contained in both loess and soil of the plateau, it has attracted geochemists, geographers, and pedologists in the world for a long time.

Studies on pedogenesis in the plateau have been extensively carried out with field surveys in the past decades, however, those on environmental geochemistry are limited and few publications can be found. The purposes of our work as the first stage of the plateau environmental geochemistry studies are: (1) to determine typical natural compositions of elements in the soils; (2) to describe the geographic patterns of compositional variation. Loesses, the parent material of plateau soils in different areas,

are quite similar in chemical composition, and chemical weathering action during soil formation was relatively weak because of the arid/semi-arid environments on the plateau. This makes it rather difficult to distinguish the variation patterns of element concentrations in the soil unless analytical methods employed are good enough in both accuracy and precision. With the advantages of multi-elements analysis, sufficient accuracy and precision as well as lower unit cost compared to other analytical methods, INAA is the right technique to meet requirements for studying of the plateau environment geochemistry.

The primary results of our study simultaneously reveal distributions of 32 elements in soils derived from loess, and clearly demonstrate geographic variations of element compositions. It is very interesting that the variable patterns also provide a pedogeochemical evidence for the aeolian theory of loess formation in China (Liu, 1985).

SAMPLING AND SAMPLE ANALYSIS

The samples used in this study represent main soil types that were developed from loess in the plateau. A total of 120 soil profiles, scattered through out most of the plateau, were sampled. All genetic horizons in each soil profile were sampled separately. The sample of each horizon is a composite of several sub-samples collected haphazardly at different positions of the horizon. Each sample was air dried, sieved through a 1-mm nylon screen, well mixed, then split into four equal parts. One quarter of the sample was pulverized in an agate mortar, and thoroughly mixed to ensure homogeneity. The entire suite of samples were arranged in a randomized sequence. Sample analysis was in that sequence to avoid confounding any inherent geographic variation with a possible systematic analytical error. Samples (40–60 mg each) were sealed in high pure aluminum bags respectively for long irradiations, or in polyethylene bags for short irradiations (200–300 mg for each sample). Standards were packed and irradiated in the same way as the samples.

Mn, V, Al, Ti, Mg and Na were analysed by short irradiation at a nuclear reactor of the Institute of Atomic Energy (IAE), China, with a fast rabbit transfer system. For determination of the other elements, samples were irradiated at the IAE reactor at a thermal neutron flux density of $5 \times 10^{13} \text{ n cm}^{-2} \text{ sec}^{-1}$ for 12 hours, counted on a ORTEC HPGe detector with a FWHM of 1.95 keV for the 1332 keV peak of ^{60}Co at the Northwestern Institute of Soil and Water Conservation (NISWC). A proper procedure developed by one of the authors in a previous study was used for the analysis of environment samples, including the optimum cooling and counting time and corrections for interferences from fission products of uranium-235 (Tian, 1987).

Table 1 Comparison of our results in SRM-GSS-8 with recommended values by IGGE (in $\mu\text{g/g}$, except Na, K, Ca, Fe, Mg, Al in %)

Element	This work ¹	IGGE (1986) Recommended values
Na	1.34 ± 0.12	1.28 ± 0.015
Mg	1.38 ± 0.11	1.44 ± 0.02
Al	6.03 ± 0.44	6.31 ± 0.04
K	1.93 ± 0.09	2.01 ± 0.02
Ca	6.80 ± 0.73	5.91 ± 0.04
Sc	11.95 ± 1.42	11.7 ± 0.4
Ti	3840 ± 480	3800 ± 50
V	77.4 ± 6.6	81.4 ± 0.8
Cr	70.8 ± 4.3	68 ± 2
Mn	626 ± 39	650 ± 9
Fe	3.36 ± 0.43	3.13 ± 0.01
Co	12.65 ± 0.52	12.7 ± 0.4
Zn	69.8 ± 13.1	68 ± 1.6
As	13.51 ± 1.36	12.7 ± 0.5
Rb	104 ± 14	96 ± 2
Sr	266 ± 34	236 ± 6
Zr	211 ± 44	229 ± 6
Sb	1.43 ± 0.24	1.04 ± 0.12
Cs	7.02 ± 0.49	7.5 ± 0.5
Ba	472 ± 70	480 ± 11
La	34.0 ± 5.4	35.5 ± 1.4
Ce	68.4 ± 2.9	66 ± 4
Nd	32.7 ± 3.2	32 ± 1.6
Sm	5.73 ± 0.67	5.9 ± 0.3
Eu	1.17 ± 0.11	1.2 ± 0.04
Tb	1.00 ± 0.22	0.89 ± 0.05
Yb	2.69 ± 0.34	2.80 ± 0.1
Lu	0.410 ± 0.038	0.430 ± 0.03
Hf	6.67 ± 0.58	7.0 ± 0.5
Ta	1.03 ± 0.14	1.05 ± 0.16
Th	11.6 ± 0.49	11.8 ± 0.4
U	3.07 ± 0.45	2.7 ± 0.2

¹ Error limits are standard deviations of the mean for 15–20 replicate analyses

The National Bureau of Standard (NBS) SRM 1633a (coal flyash), an ideal standard for use as a multi-element standard with advantages of the chemical homogeneity and sufficient concentrations of most elements in it (Korotev, 1987), was used as a primary standard in this study. To evaluate the accuracy of the determinations, GSS-8, prepared by the Institute of Geophysical and Geochemical Exploration (IGGE), China, was selected as the secondary standard in each batch of samples. GSS-8 has a similar composition to soil samples of the plateau, and more than sixty recommended values by IGGE are available. In fact, GSS-8 is a loessic soil material collected from Luochuan at the center part of the plateau (Xie, 1985), so that GSS-8 data analysed by INAA in this study can well express the accuracy and precision of the analysis for the soil samples.

The agreement between our data and the recommended values of GSS-8 is satisfactory (Table 1). The relative difference for most elements is less than 5%. Only those for Ca, Sr, Sb, Tb, U exceed 10%. It may be partly due to the chemical homogeneity problems of SRMs in small samples as observed in previous studies (Korotev, 1987).

RESULTS AND DISCUSSION

Concentrations of soil elements

32 elements in the soil samples have been determined by INAA. Table 2 shows the mean concentrations of elements in the plateau surface soil.

Abundances of elements in the earth upper crust (Taylor, 1981; 1964) and the median values of soil element concentrations in the world (Bowen, 1979) are also listed in the table for comparison. Overall, the surface soils are uniform in composition with the limited coefficients of variation in the table. This further suggests the loess as the soil parent materials in the plateau has a compositionally similar sources (Tian, 1987; Wen, 1989). The concentrations of the plateau surface soil significantly differ from the median values of the world soils, while relatively close to the estimates of the crust abundances. This reflects the facts that the parent materials of the soil have been widely exposed to the surface by severe soil erosion and human activities on the plateau so that loess, with similar chemical abundances to the upper crust (Wen, 1989), dominates the mean concentrations of elements in the surface soil. The soil in the plateau was enriched in Na, Mg, Ca in comparison to the world soil. It is likely due to the environment, in which the soil was generated, was arid/semi-arid so that much more mobile elements remained in the top soil. The rather higher concentrations of arsenic and cesium in the plateau soil compared to those either in the upper crust or in the world soil show special geochemical characteristics of soils in the plateau.

**Table 2 Comparison of mean concentrations of elements in surface soils of the plateau
(in $\mu\text{g/g}$, except Na, Mg, Al, K, Ca, Ti, Fe in %)**

Element	The plateau*			The earth upper crust	Median values of soil in the world
	Mean	S.D.	C.V., %		
Na	1.30	0.19	14.54	2.82	0.5
Mg	1.25	0.20	15.79	1.39	0.5
Al	6.33	0.55	8.66	8.47	7.1
K	2.06	0.42	20.3	2.74	1.4
Ca	4.31	1.86	43.1	2.50	1.5
Sc	11.2	1.63	14.6	10	7
Ti	0.345	0.060	17.4	0.360	0.5
V	75.6	10.5	13.9	60	90
Cr	67.3	9.34	13.9	35	70
Mn	616	90	14.7	600	1000
Fe	2.95	0.55	18.5	3.50	4.0
Co	11.9	2.13	17.9	10	8
Zn	69.3	21.3	30.8	52	90
As	12.0	2.18	18.1	1.8	6
Rb	94.6	13.1	13.8	110	150
Sr	175	68	39.3	350	250
Zr	246	72	29.2	240	400
Sb	1.02	0.22	22.0	0.2	1
Cs	7.02	1.82	25.3	3.70	4
Ba	484	60	12.4	700	500
La	34.8	5.68	16.3	30	40
Ce	63.9	9.0	14.1	64	50
Nd	31.8	6.1	19.3	26	35
Sm	5.55	0.89	16.0	4.5	4.5
Eu	1.16	0.14	11.7	0.88	1
Tb	0.887	0.20	22.5	0.64	0.7
Yb	2.77	0.39	13.9	2.2	3
Lu	0.419	0.056	13.2	--	0.4
Hf	7.65	1.74	22.8	5.8	6
Ta	1.03	0.16	15.2	2	2
Th	11.4	1.70	15.4	10.5	9
U	2.45	0.47	19.2	2.5	2

* Summary statistics given as arithmetic means, standard deviations (S.D.), and coefficients of variation (C.V.)

Distribution patterns of elements

Statistic analysis methods were used to study distribution patterns of elements in soils on the plateau. The results have exhibited our data from INAA are precise enough to distinguish both regional and vertical (i.e., among horizons) element distribution patterns even though the compositional variations are minor. As an example, here introduced are the geographic patterns of compositional variation in the surface soil.

Regional elemental distributions were divided into the following three main patterns by using the method of trend surface analysis. Most of the elements, e.g., Fe, Co, Cr, As, Zn, REs, Th, Ta, Cr, Mn, Al, Sc, Rb, Cs and Mg have shown a clay-related pattern. Concentrations of these elements increase from the north to south on the plateau with the same trend as contents of clay in the soil. Cobalt contour plot (Fig. 1) typically displays this pattern. This suggests that the content of clay fraction is a main factor affecting element distributions in the soil. However, in comparison among the plots of those elements, the patterns of contours are different from each other to a certain extent. For instance, the contour of zinc differs from that of cobalt in the south part of the plateau besides the general trend. The phenomena of

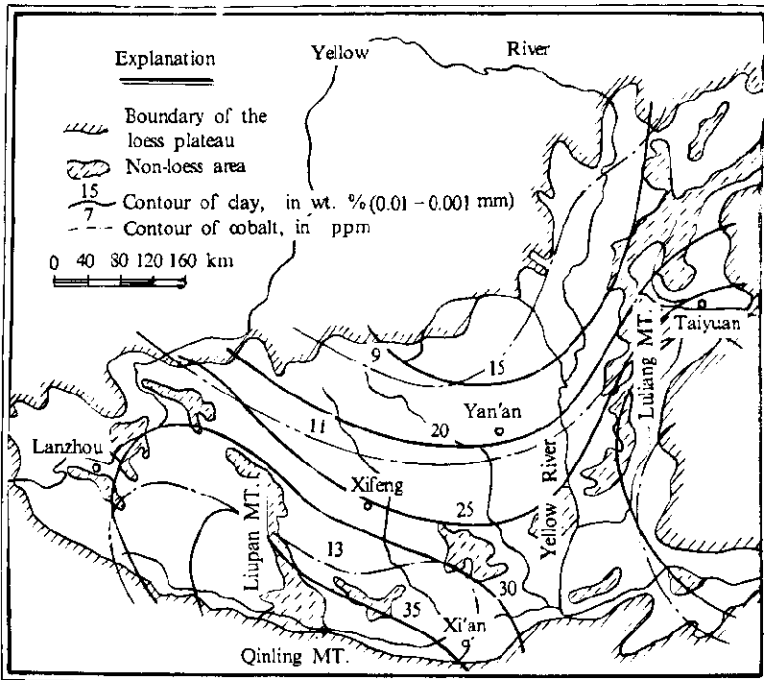


Fig. 1 Contour maps of the trend surface for cobalt and clay fraction in top soil of the loess plateau

partial and local differences among the plots may be caused by the different geochemical behaviors of individual element in the surface environment. It is believed that zinc in oxidizing condition is relatively mobile and accumulated on calcium barrier (i.e. on Bca horizon in which the CaCO_3 surface appears to constrain the absorbed Zn to conform a cobonate structure), but this is not true for cobal (Papadopoulos, 1989; Beus, 1982).

Stable elements like Zr and Hf belong to the second pattern. A plot for Hf is shown in Fig. 2. On contrary to the first pattern, the concentrations of Hf in the soils decrease from north to south with a trend similar to the content of silt fraction in the soil. This phenomenon fits the results obtained from previous studies of loess, in which it was found that anti-weathering minerals containing the elements in this group were enriched in the loess of the north and depleted of the south (Liu, 1966).

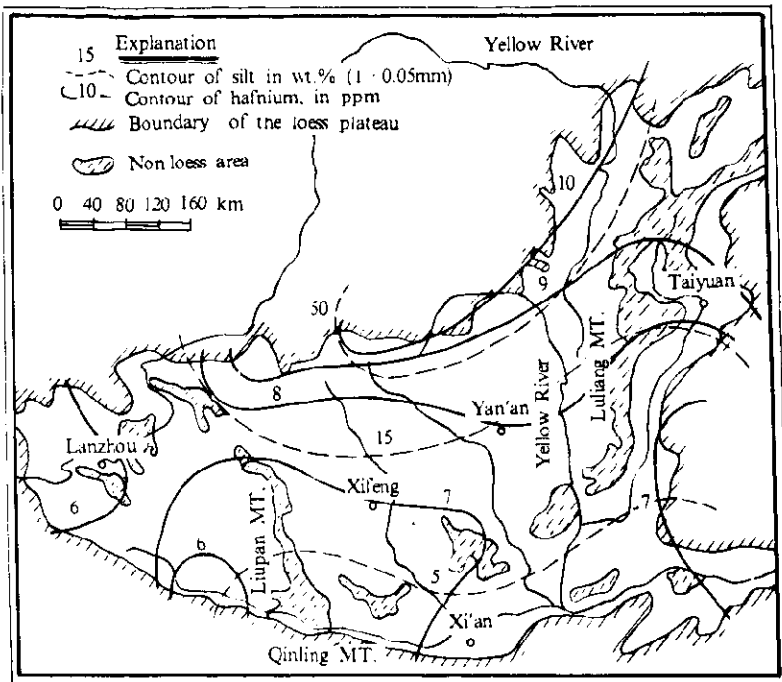


Fig. 2 Contour maps of the trend surface for hafnium and silt fraction in top soil of the loess plateau

Geologists have made extensive studies of loess in China, and established the aeolian theory (Liu, 1985). According to the theory, the source of loess materials is mainly located to the north/west of the plateau and the materials were transported by

wind, deposited on the plateau with grain size fractionations in the process of transportation. Both patterns mentioned above further confirm the theory by the fact that the variations of element concentrations are down-wind of the source, and the contours in the figures indicate the direction and the passing way of the transportation.

The third pattern shows the distributions are more obviously affected by bioclimatic environment in which the soils were generated. Elements exhibiting this pattern are Ca, Sr and Na. They are apparently depleted in the south of the plateau and other areas with better vegetations, and enriched in the west and / or the north where the climate is much more arid than that in the south. However, the distributions of these elements were also affected by the grain fraction of soils. However, it was not only so apparent as that in the group one or two. The contours for these elements (not presented in this paper) are not so regular as those for the elements in the previous patterns, and the contours of lower concentrations appear in the south part of the plateau and / or scatter in the areas with good vegetations.

REFERENCES

- Beus, A.A., Environmental geochemistry, Beijing: Science Press, 1982:60
Bowen, H. J. M., Environmental chemistry of the element, London:Academic Press, 1979
Korotev, R.L., J. Radioanal. Nucl. Chem., 1987, 110(1):159
Korotev, R.L., J. Radioanal. Nucl. Chem., 1987, 110(1):179
Liu, T.S., Material composition and structure of loess, Beijing: Science Press, 1966:192
Liu, T. S., Loess and the Environment, Beijing: China Ocean Press, 1985: 9
Papadopoulos, P. and Rowell, D.L., J. Soil Science, UK, 1989, 40(1): 39
Taylor, S.R. and McLennan, S.M., Phil. Trans. Roy. Soc., 1981, A301: 381
Taylor, S. R., Geochim. Cosmochim. Acta, 1964, 29: 1243
Tian J.L., Chou C. L.; Ehmann, W.D. , J. Radioanal. Nucl. Chem., 1987, 110(1):261
Wen, Q. Z., Geochemistry of loess in China, Beijing: Science Press, 1989, 1: 276
Xie, X. J., Yan, M.C., Li, L.Z. and Shen, H.J., Geostandards Newsletter, 1985, 2: 227

(Received May 24, 1991)