

# Hg Geochemical Character on Soil of Xianling of Ming Dynasty

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**Abstract**—we investigated characteristics of soil Hg, soil gas Hg and atmospheric Hg on tomb of Ming Xianling. Xianling is the tomb of the fourth emperor Zhu Gaochi of the Ming Dynasty. Soil samples were collected for determination of mercury. Soil gas Hg and atmospheric Hg is analysed on high mercury anomalous areas. The results showed that soil Hg on Treasure Town is close to natural background and on Five Offerings is enriched or anomalous. The content of soil Hg is enriched in the surface soil layer. Soil gas Hg is high on Hg enrichments. Atmospheric Hg is low on the survey areas. Meteorological conditions influence mercury flux of emission from Soil to atmosphere. Soil gas Hg is directly affected by the soil Hg. In history, the use of mercury in the mausoleum is a very common phenomenon. Study on the geochemical characteristics of mercury provides the scientific basis for environmental protection and historical research.

**Keywords**—Ming Xianling; soil Hg; soil gas Hg; atmospheric Hg; tomb

## I. INTRODUCTION

According to the archaeological and historical record, the use of mercury in the mausoleum is a very common phenomenon. Mercury and mercury minerals as anticorrosion material, pigment, drug or the status symbol in and around the tomb becomes a different source of mercury from geological bodies[1]. Mercury and cinnabar[2] buried in the soil for a long time. Due to volatile features of mercury[3], gas mercury constantly emitted from soil. Gas mercury was adsorbed by soil in the

way up and became anomalous. Using mercury measurement to study the content of soil Hg, soil gas Hg[4] and atmospheric Hg[5], the geochemical characteristics of mercury provides the scientific basis for environmental protection[6] and historical research[7].

Lying in Changping District of Beijing, the Ming Tombs are a group of mausoleums for 13 emperors in the Ming Dynasty. It is the extant imperial mausoleum building complex in China that has the largest number of the imperial mausoleums for emperors and empresses.

Xianling is the tomb of Emperor Zhu Gaochi, the fourth ruler of the Ming [8], and his wife Empress Zhang. Emperor Zhu Gaochi was comparatively thrifty in his expenditures, which could be reflected from his small-scaled Xianling Tomb. The tomb covers an area of 42,000 square meters. The main structures, in turn, are Tomb Gate, Gate of Eminent Favor, Hall of Eminent Favor, Gate on the Threshold of Stars, Five Stone Sacrificial Utensils, Soul Tower, and Treasure Town. The Underground Palace is under the Treasure Town.

Soil samples were collected for determination of mercury on Treasure Town, Five Offerings areas and around tomb.

Soil Hg is analysed by Atomic Fluorescence Spectrometry. A variety of methods of mercury vapor survey[9] were carried out for mercury in air and mercury in soil gas on high mercury anomalous area. Soil gas Hg and atmospheric Hg is analysed by the atmosphere of ultra trace mercury analyzer.

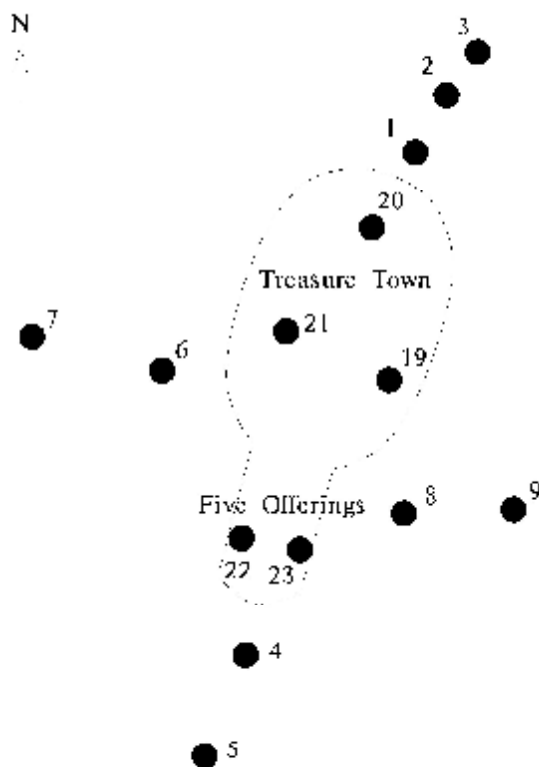


Figure 1. Example of a ONE-COLUMN figure caption.

## II. DISCUSSED PROBLEMS

### A. Characteristics of soil Hg

Soil samples were collected on Treasure Town. From No.19,20 to 21, Figure 1, which are located in the East, North and West of Precious Top in turn. The content of soil Hg is 0.347 $\mu\text{g/g}$ , 0.153 $\mu\text{g/g}$  and 0.151 $\mu\text{g/g}$ . They are higher than the soil Hg background value 0.065 $\mu\text{g/g}$  of China. The Soil pH value is less than 6.5.

According to environmental quality standard for soil, soil Hg of No.20 and 21 is closed to the natural background value of soil 0.15 $\mu\text{g/g}$  [10]. Soil Hg of No.19 comes up to the second standard. Soil Hg is enriched or anomalous in the surface soil on Treasure Town.

Comparison of 0-10cm and 10-20cm in soil samples found that Hg is enriched in the surface soil. The content is showed in Table 1. The content of soil Hg is 0.347 $\mu\text{g/g}$  in the 0-10cm and 0.231 $\mu\text{g/g}$  in the 10-20cm for No.19. The content of soil Hg in the 10-20cm is higher than the soil Hg background value of China. The Soil pH reduces from 6.46 to 5.78.

The content of soil Hg is 0.153 $\mu\text{g/g}$  in the 0-10cm and 0.077 $\mu\text{g/g}$  in the 10-20cm for No.20. Soil Hg is close to background value of China. The Soil pH reduces from 5.44 to 5.36. Results indicate that the content of soil Hg is enriched in the surface soil layer.

High mercury anomalous area was detected on Five Offerings. The results are showed in Table 1. The content of soil Hg is 1.845 $\mu\text{g/g}$  for No.22. Soil pH is 7.22. Soil samples were collected in the 0-10cm layer and soil composed of gravel. The content of soil Hg is 3.062 $\mu\text{g/g}$  for No.23. Soil pH is 8.10. Soil samples were collected in the 0-20cm layer. The composition of soil includes lime, sand and brick. According to environmental quality standard for soil, soil Hg of No.22 and 23 comes up to the third standard.

The composition and properties of soil on Treasure Town are different from Five Offerings areas. Soil pH and soil Hg are higher on Five Offerings areas.

TABLE I. CONTENT OF SOIL Hg AND pH IN TOMB

No.	Soil Hg( $\mu\text{g/g}$ )	pH	Layers(cm)	Areas
19	0.347	6.46	0-10	Treasure Town
	0.231	5.78	10-20	
20	0.153	5.44	0-10	Treasure Town
	0.077	5.36	10-20	
21	0.151	6.14	0-20	Treasure Town
22	1.845	7.22	0-10	Five Offerings
23	3.062	8.10	0-20	Five Offerings

Soil samples were collected to survey mercury enrichments or anomalies around tomb. The results are showed in Table 2. The content of soil Hg is 0.091 $\mu\text{g/g}$  in the North, 0.566 $\mu\text{g/g}$  in the South, 0.327 $\mu\text{g/g}$  in the West, and 0.515 $\mu\text{g/g}$  in the East.

Soil Hg in the North is close to background value of China. In the peripheral section, the content of soil Hg is enriched near the tomb and reduces to background value away from tomb.

TABLE II. CONTENT OF SOIL Hg AND pH AROUND TOMB

No.	Soil Hg( $\mu\text{g/g}$ )	pH	Layers(cm)	Position
1	0.091	7.79	0-40	North
2	0.083	7.61	0-40	North
3	0.071	7.66	0-40	North
4	0.566	8.54	0-40	South
5	0.258	8.66	0-40	South
6	0.327	8.40	0-40	West
7	0.250	8.30	0-40	West
8	0.515	8.23	0-40	East
9	0.025	7.92	0-40	East

### B. Features of soil gas Hg and atmospheric Hg

We measured soil gas Hg and atmospheric Hg on high mercury anomalous area of Five Offerings. The results are showed in Table 3 and Table 4.

The monitoring parameters of No.22 are time from 15:40 to 16:40, average temperature 31.1 $^{\circ}\text{C}$ , average soil temperature 36.9 $^{\circ}\text{C}$ . Soil gas Hg decreased from 57.383  $\text{ng/m}^3$  to 43.590  $\text{ng/m}^3$ . Hg concentration in atmosphere declined from 9.453  $\text{ng/m}^3$  to 4.538  $\text{ng/m}^3$ . Then the data did not obviously change any more.

The monitoring parameters of No.23 are time from 17:00 to 18:00, average temperature 29.1°C, soil temperature from 28.3°C to 24.6°C. Soil gas Hg decreased from 6.430 ng/m<sup>3</sup> to 5.632ng/m<sup>3</sup>. Atmospheric Hg decreased from 4.352 ng/m<sup>3</sup> to 3.362 ng/m<sup>3</sup>. Then the data held the line.

Soil gas Hg is large different on the monitoring points of high mercury anomalous area. The content changed from 57.383 ng/m<sup>3</sup> to 5.632ng/m<sup>3</sup>. Atmospheric mercury distributes evenly in the air. The highest content of soil gas Hg is 10 times of atmospheric Hg. The data of soil gas Hg are far lower than the average content 559.65ng/m<sup>3</sup> of Beijing urban[11]. Hg concentration in atmosphere is same as the average content 3.13ng/m<sup>3</sup> of Beijing urban[11].

A good linear relationship for soil gas Hg versus atmospheric Hg was confirmed, which indicated that the sources of soil gas Hg may be the more significant contributors of mercury to the atmosphere than previously realized[11].

Although meteorological conditions[12] influence mercury flux of emission from Soil to atmosphere, Soil gas Hg is directly affected by the soil Hg.

At the same monitoring spot, air temperature is maintained constant. During the monitoring period, temperature changed from 31.1°C to 29.1°C and soil temperature sharp declined from 37.7 °C to 24.6°C. The total radiation intensity reduced from 467.1W/m<sup>2</sup> at 15:40 to 8.8W/m<sup>2</sup> at 18:00. In the monitoring period, soil moisture, relative humidity and windspeed kept stable. The result is showed in Table5. Soil temperature is one of the important factors affecting the result of soil gas mercurometric survey.

TABLE III. CONTENT OF SOIL GAS Hg IN DIFFERERNT MONITORING PARAMETERS

No.	Atmospheric Hg(ng/m <sup>3</sup> )	Time	Soil temp.(°C)	Temp.(°C)
22	9.453	15:40:00	33.2	31.3
	7.507	16:00:00	37.4	31.3
	6.510	16:20:00	37.7	30.8
	4.538	16:40:00	37.6	30.9
23	4.352	17:00:00	28.3	30.7
	3.681	17:20:00	25.9	29.6
	3.372	17:40:00	24.9	28.5
	3.362	18:00:00	24.6	27.9

TABLE IV. CONTENT OF ATMOSPHERIC Hg IN DIFFERERNT MONITORING PARAMETERS

No.	Soil Gas Hg ng/m <sup>3</sup>	Time	Soil temp.(°C)	Temp.(°C)
22	57.383	15:50:00	37.4	31.8
	48.727	16:10:00	37.3	31.1
	43.590	16:30:00	37.8	31.0
23	6.430	17:10:00	26.8	30.0
	6.103	17:30:00	25.3	29.0
	5.632	17:50:00	24.7	28.1

TABLE V. TOTAL RADIATION INTENSITY AND TEMPERATURE

Time	Total Radiation Intensity(W/m <sup>2</sup> )	Soil Moisture (%)	Relative Humidity (%)	Windspeed (m/s)
15:40	465.3	5.07	39.3	0.8
15:50	467.1	5.72	38.2	0.8
16:00	445.8	5.76	38.3	1.0
16:10	437	5.76	39.5	0.7
16:20	422.6	5.77	40.6	0.7
16:30	389.2	5.77	40.1	0.6
16:40	360.3	5.78	39.5	0.6
17:00	142.8	7.92	38	0.7
17:10	193.1	7.89	40.4	0.6
17:20	75.3	7.86	42.6	0.6
17:30	25.4	7.84	43.2	0.6
17:40	13.9	7.81	44.3	0.5
17:50	11	7.81	46.3	0.4
18:00	8.8	7.81	47.2	0.3

### III. CONCLUSIONS

Mercury enrichments or anomalies in soils are a general phenomenon in Chinese, and investigation on source, transport cycle and fate of Hg in soil is essential for evaluating environmental. The mercurometric survey was employed to detect or judge the mercury character of tomb. Mercury vapor measurement has yielded preliminary results in the detection of mercury source.

There are mercury enrichments or anomalies in soils of Xianling tomb. The average content of soil Hg is closed to the natural background on Treasure Town. Soil Hg on Five Offerings is anomalous. The content of soil Hg comes up to the third standard.

Soil gas Hg is high on areas of anomalous soil Hg and is far lower than the average content of Beijing urban. The sources of soil Hg may be the more significant contributors of mercury to the soil gas. Hg concentration in atmosphere is same as the average content of Beijing urban.

Meteorological conditions influence mercury flux of emission from Soil to atmosphere. Soil temperature is one of the important factors affecting the result of soil gas mercurometric survey.

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